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SPACE SCIENCES LABORATORY

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AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA USING REMOTE SENSING TECHNIQUES

A report of work done by scientists of 4 campuses of the University of California (Davis, Berkeley, Santa Barbara and Riverside) under NASA Grant NGL 05-003-404

Semi-annual Progress Report
31 December 1975
Space Sciences Laboratory
Series 17, Issue 19

UNIVERSITY OF CALIFORNIA, BERKELEY

AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA USING REMOTE SENSING TECHNIQUES

Principal Investigator:
Robert N. Colwell

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during the period covered by this progress report, research efforts under our integrated multi-campus study have continued to be concentrated on California's water resources along the lines set forth, at NASA's request, in our statement of 30 September, 1973. The block diagram of Figure 1-1 provides a good overview of both the concept embodied in this integrated study and the various components of it. As indicated by that figure, our integrated study of California's water resources continues to concern itself primarily with the usefulness of remote sensing in relation to two categories of problems: (1) those pertaining to water supply (dealt with primarily by personnel of the Davis and Berkeley campuses as reported upon in Chapter 2a and 2b, respectively); and (2) those pertaining to water demand (dealt with primarily by personnel of the Santa Barbara and Riverside campuses as reported upon in Chapters 3 and 4, respectively).

Opportunities which we are exploiting to the fullest in our attempt to achieve true integration of this multi-campus project stem from the following fact that repeatedly manifests itself: many of the techniques and methodologies developed by those of our group who are concerned with water supply problems can, with only slight modification, be used by those of us who are concerned with water demand problems, and vice versa. Examples can be found of this in three major areas of the work dealing with water supply problems, as reported upon in Chapter 2a by Dr. Algazi et al of the Davis campus, viz. those dealing respectively with (1) sensitivity analyses of watershed models, (2) acquisition of hydrologic parameters by remote sensing, and (3) basic studies of signal processing algorithms pertinent to remote sensing applications. Reciprocally, this same inter-relationship also applies with reference to two aspects of the work dealing with water demand problems, as reported upon by Estes et al in Chapter 3, viz. those dealing with (1) assessment of the semi-operational use of remote sensing in relation to a water demand model, and (2) cost-effectiveness comparisons of remote sensing vs. conventional methods of acquiring water demand information. Further evidence of the integration of water supply and water demand aspects of our study is found in the work reported upon in Chapter 4 by Bowden et al of the Riverside campus. Although the bulk of the work of that group deals with remote sensing as an aid in water demand assessment, they state that water supply considerations can have far-reaching implications in the economic, social and geographic sectors. This is a doubly important consideration because, on the one hand, imported water serves, for the most part as the economic life-blood of the region in that it is vitally needed for both agricultural and domestic purposes. On the other hand Southern California has a large though inadequate water supply of its own. As these investigators aptly state in Chapter 3, "the relationship of these two water supply sources affects the quality of life and to some extent the food supply of this highly populous area".

As will be evident from a reading of Chapter 5, our Social Sciences Group also contributes greatly to the integration of our multi-campus study. That group asserts: "With the California Water Project as our

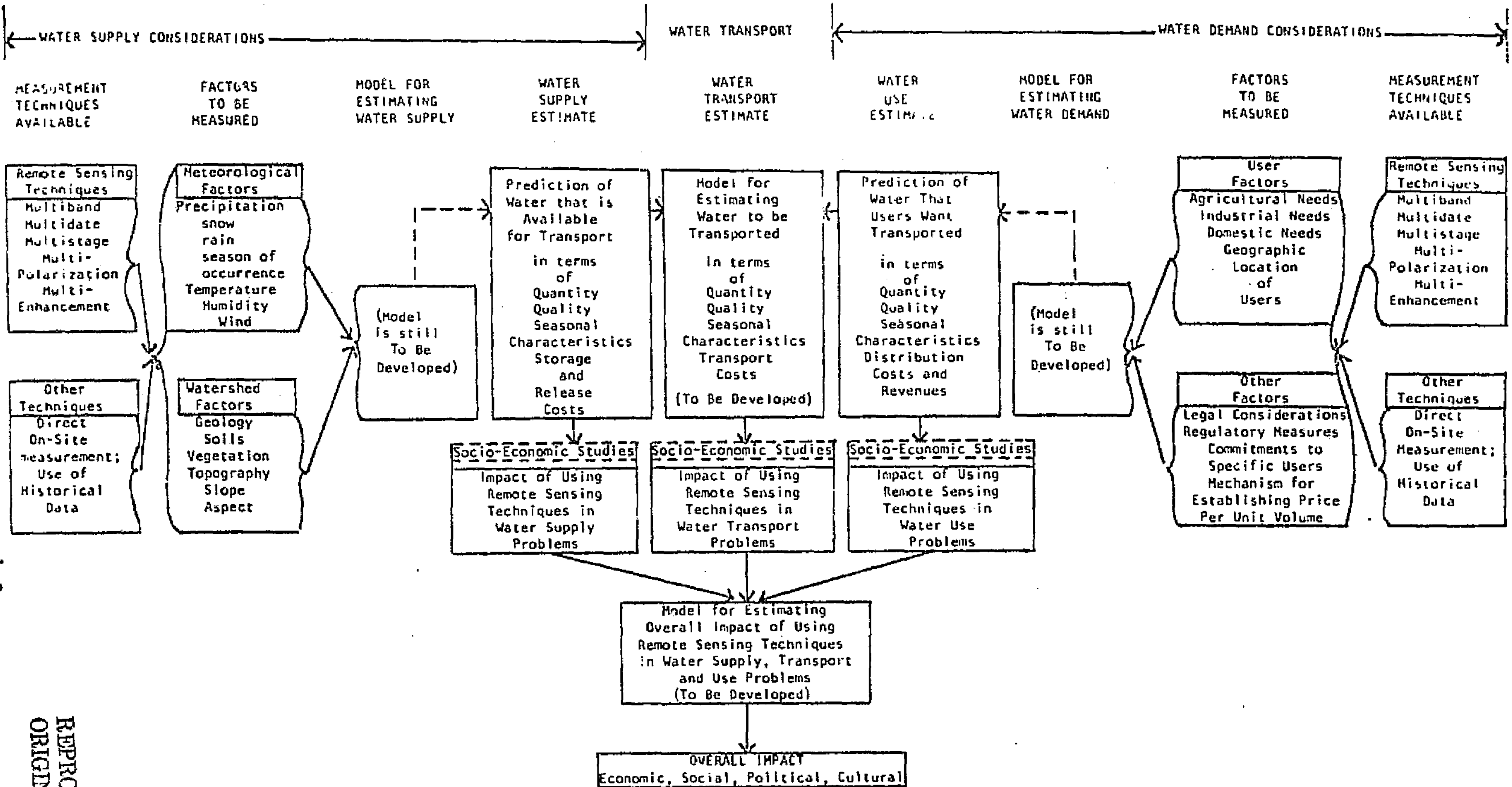

FIGURE 1.1 Block diagram indicating the factors which relate to water supply, water transport, water use and water impact. For a discussion of the proposed remote sensing studies in relation to this diagram, see text.

primary, but not exclusive, focus, we try to develop insights into the very complicated web of factors impinging on the management of resources in order to learn how new sources of information can be accomodated, by whom, and for what purpose. It is patently clear that these decisions do not take place in a technological, economic, political and social vacuum; decisions regarding resources take place in a real-life, rapidly changing environment. Our task is, therefore, to map the social landscape, the better to learn where, how, and to what effect new sources of information can prove their mettle."

In recent years it has become increasingly apparent to our project's remote sensing scientists that a lack of "technology acceptance" by resource managers and others very often constituted a major deterrent to the achieving of something of practical value from our research. It therefore became apparent that the most significant of our own findings should be integrated with those of our remote sensing colleagues elsewhere, preferably through the publication of some kind of definitive remote sensing "manual". We all recognized that if such a document, well illustrated, were to be prepared under auspices of some professional group of high repute, (such as the American Society of Photogrammetry), and made quite generally available in highly comprehensible form, much would be done to achieve the necessary technology acceptance.

Such an effort also would do much to stem the criticism that we sometimes have heard to the effect that many of our NASA-funded research findings remained buried in progress reports, never to be seen by resource managers and other potential users of modern remote sensing technology.

Pursuant to this thought, we will conclude this introductory chapter by inviting attention to the unusually substantial contribution which those involved in our integrated study have been making to the "Manual of Remote Sensing" which has just been published under auspices of the American Society of Photogrammetry. Collectively speaking, our contribution to this first definitive and authoritative treatment of remote sensing ranges from co-editorship of the entire Manual, through authorship of its introductory chapter and co-authorship of several other chapters, to the menial tasks of providing large amounts of illustrative material and of proof-reading manuscripts. Now that the Manual has been published, it should be apparent to any interested reader, as it now is to us, that our findings to date under this integrated study provide some of the most compelling evidence, both qualitative and quantitative, for the adoption by resource managers of modern remote sensing techniques.

Chapter 2(a)

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CHAPTER 2(a)

Co-Investigator: R. Algazi

Contributors: M. Suk, A. Bhumiratana, J. Stewart, B. Romberger, K. Illis, G. Ford, R. Eid

2a.0 Introduction

In the past two years, the research conducted under this grant has been focused on the application of remote sensing techniques to water resources. Our group has given special attention to problems germane to the supply of water in California, to the implementation and analysis of hydrologic models and to the determination by remote sensing of some of the physical parameters which characterize the state of the watershed and the evaluation of the snowpack. In addition to our performing this systems engineering and modeling work we have continued our technical work, as digital signal processing, funded in a significant part by the National Science Foundation. We report here on our work in the past year and principally since our May 1975 Annual Report. Significant results have been obtained in the following areas.

A. Implementation and sensitivity analysis of some watershed models amenable to remote sensing inputs.

B. Acquisition of hydrologic parameters by satellite remote sensing.

C. Basic studies of signal processing algorithms pertinent to remote sensing applications.

To facilitate the reading and understanding of this report, we have used appendices for lengthy and self-contained studies. This allows proper emphasis in the body of the report on the significance and use of these results for the objectives of the grant.

2a.1 Implementation And Sensitivity Analysis of Hydrologic Models

We have undertaken in the past year a study of various watershed models which are used operationally or which are given most serious consideration in technical literature.

We started our work with a study of the technical literature, and of reports on work done or applications of remote sensing to hydrology.* From this work, it became apparent that the work most germane to our interest was that of Ambaruch and Simmons (1) on the use of remote sensing in the Kentucky

*See a discussion of hydrologic models in the May 1975 Report.

A comprehensive discussion of our results is presented in Appendix A. These results are still tentative and will require some additional effort to put them in a useful and easily readable form. We expect to be able to achieve this objective by May, 1976.

To indicate the nature of our result we summarize briefly here some of our findings.

ANALYSIS: Behavior of Model: We found that the dynamics of the model and the weather of California lead to four regimes denoted as Winter, Spring, Summer, Fall. For each regime we get: a) Simpler Behavior of the Model; b) Insensitivity to Some Parameters.

PERFORMANCE INDICES: We are considering different indices which correspond to different uses of the hydrologic model: Peak Daily Runoff, Storm Volumetric Runoff, Monthly Volume Runoff, Low Flow.

PARAMETERS STUDIED: We have considered dynamic parameters or inputs which are measured or estimated daily or seasonally. These parameters are Precipitation (PCPTM) which includes the effect of rainfall and snowmelt and Evapotranspiration (ED). We have also studied the sensitivity of the Performance Indices to the change of some model parameters such as the Lower Zone and the Upper Zone Tension Water Capacity (LZTWM and UZTWM), the percent of the watershed in impervious area (PCTIM) and the percent of the watershed in riparian vegetation, streams and lakes (SARVA).

SENSITIVITY: For one of the performance indices, monthly runoff, the sensitivity of the model to the parameters studied is summarized in Table 1. This table shows, for each of the regimes of the model, the variation in monthly runoff resulting from a variation of one of the parameters studied. To illustrate the use of these sensitivity results, consider the effect of PCPTM during the Spring regime, in which the sensitivity S is about 1. PCPTM is then the combined effect of rainfall and snowmelt. A 10% variation in this parameter will result in a 10% variation in the monthly runoff forecasted by the model. By contrast the same 10% variation in PCPTM during the Fall regime may result in a 40% change in monthly runoff (sensitivity as high as 4).

The situation is in general more involved than is indicated in Table 1 and more details are given in Appendix A.

Still, we can obtain from Table 1 some information as to the critical parameters to be acquired by remote sensing and also as to their timing. For the forecasting of monthly runoff, there are two factors (PCPTM at all times of the year, and EVAPT, principally for the Spring regime), which are the most pertinent. Since snowmelt contributes to PCPTM, the forecast of snowmelt also has a special importance.

More definite conclusions of this study will be presented in the annual report.

2a.2 Determination of Parameters Pertinent to Hydrologic Models from Satellite Data

2a.2.1 Introduction

We have concentrated our work to date on parameters which are most pertinent to snow hydrology.

A substantial number of studies on the areal mapping of snow using remote sensing have been undertaken in the past few years (2, 3, 4) which have evolved into a handbook of techniques for satellite snow mapping (5) sponsored by NASA. These techniques are being used quasi-operationally in several regions of the United States and in particular by the California Cooperative Snow Survey Program of the Department of Water Resources.

We note that most of the physical basis for snow ablation has been understood and modeled for a number of years (6).

On the basis of all the information available, the following physical qualities appear of prime interest in the modeling of basinwide snowmelt: the temperature, albedo, topography, areal extent of snow, spatial distribution of precipitation, and snowcover. Further, it is well known that these parameters vary substantially across the snow-covered area and change fairly rapidly with time. On that basis we have undertaken a study to incorporate satellite data into a physically based, distributed model of snowmelt in runoff prediction. We have obtained some partial technical results.

2a.2.2 Data Gathering and Correction

Since the snowpack evolves quite rapidly it appeared to us from the start that we needed in our work the frequency of coverage provided by the NOAA-3 and -4 satellites. Further, at this time, only the NOAA satellites provide data in a thermal IR band as well as in a visible band. We thus proceeded to gather all usable data collected by the NOAA-3 or NOAA-4 satellites over California, in both the visible and the thermal infrared spectral regions, from April 1, 1975 to July 8, 1975. More than 20 dates are available, corresponding to more than 40 digital tapes, recorded by NOAA at 1600 bits per inch (BPI). Our task involved converting the 1600 bits per inch digital tapes to 800 bits per inch, then extracting the needed information. This data extraction must be carefully done so that the corresponding visible and thermal images are in registration. To ensure this, we first align the corresponding images as closely as possible by eye; then we select a portion of the image which has sharp contrast, such as the coastline around the bay, and compute the cross-correlation over these corresponding regions. The maximum cross-correlation determines the amount of translation required. It appears that we can bring the registration to within $\pm$ one pixel both horizontally and vertically.

An attempt also was made to align images for different days, but due to the order of distortion of the image which is different for each day, the best we could hope for was to be able to extract data for the same general region of California for all dates. This could be improved if a geometric correction of the data were to be made before an extraction. Thus, we needed some procedure for geometric correction.

2a.2.2.1 Geometric Correction

Because of the highly distorted view of the earth provided by the NOAA satellites and to a lesser extent by the LANDSAT satellites, geometric correction of the data is mandatory. This geometric correction is needed for one of two purposes. The first is to obtain satellite data for a ground truth station. The second is to transform satellite data into map compatible data. For both purposes we have made use of a least squares fitting program using biquadratic fitting polynomials. At least six ground control points are needed for this geometric correction. Because of the difficulty of locating land features on NOAA-3 or NOAA-4 images one has to use an area at least as large as the state of California in the correction procedure. At this time we have residual geometric errors of the order of 2 pixels. These residual errors result in a fundamental limitation on the fineness of the distributed model which can be developed.

2a.2.3 Radiometric Calibration and Correction

NOAA has provided a calibration procedure for converting numerical values or counts, provided on digital tape, into temperature, as recorded by the satellite. This procedure involves converting count into voltage then voltage into temperature. It requires the use of information on the tapeheader (space view average, voltage wedge, etc.). Unfortunately, the tapes we received from the NOAA-NESS satellite field receiving station in Redwood City contained an error in the valuable tapeheader; thus NOAA's calibration procedure lead us to an unreliable result. With information from other receiving stations, we learned that the error occurs only in the voltage wedges, and that the conversion of voltage to temperature is fairly uniform for different lines and different dates. We have spent a large amount of time and effort in trying to correct these errors and after a number of false starts have finally developed a technique which produces useful results. The space view average count-to-voltage correspondence which may need to be provided in the data, was missing. By assuming a constant count for the space view average which corresponds to 5.8 volts, and that the faulty voltage wedge still indicates the true slope between count and voltage, we can estimate the true voltage wedge. The result appears to give a calibration procedure within $\pm$ 1 count. Therefore, NOAA's calibration procedure can be used to convert the count into temperature.

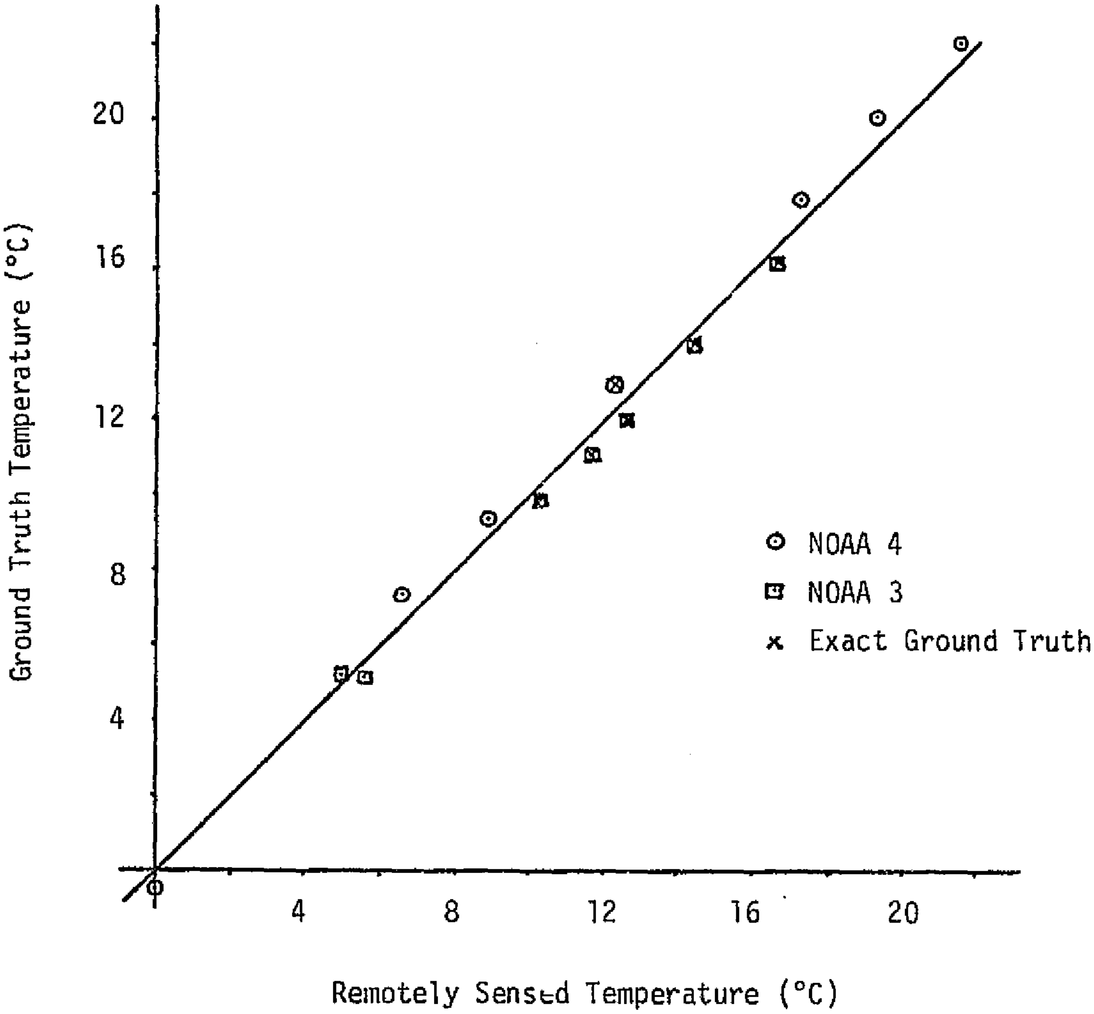

Figure 1 : Correlation of Remotely Sensed and Ground Truth Temperature

The temperature of points for which we do not have exact ground truth, is estimated by interpolation in time of exact ground truth temperatures.

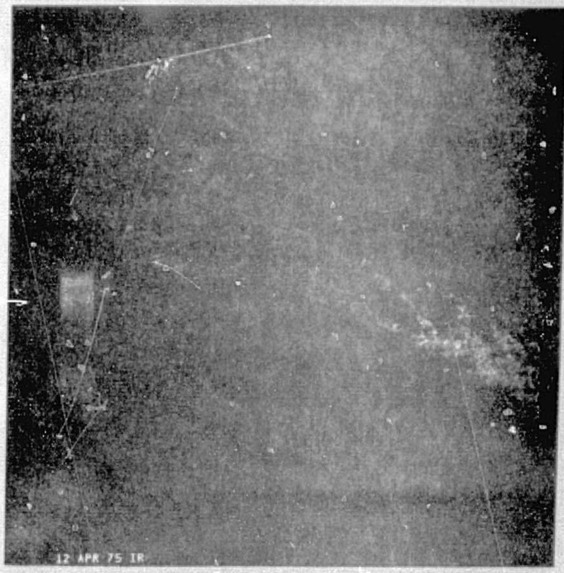

Figure 2. Snow area as determined by a brightness threshold.

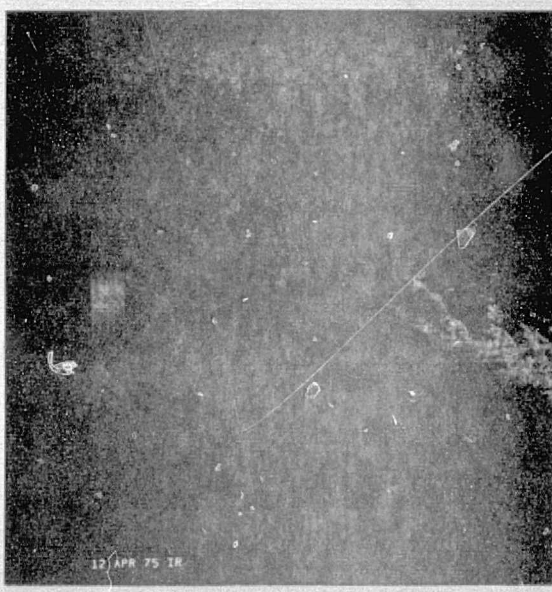

Figure 3. Snow area as determined by a $0^{\circ}C$ threshold.

The limb darkening correction is a deterministic data correction for atmospheric effects. As the nadir angle of the satellite sensors varies during a scan line, the effects of the atmosphere will also change. In the thermal band the correction needed is discussed by Smith et al (7) and we used a semiempirical formula also used by Stevenson and Miller (8).

$$\Delta T\ (-26.81 \pm 0.107T)e^{0.00012\phi^2}$$

in which ΔT is the correction to the recorded temperature T(°K) and ϕ is the nadir angle (°arc). For nadir angles of less than 30°, the angular correction is of second order. Random radiometer errors and banding or stripping errors are also present in the data. We have developed a two dimensional filtering program which substantially reduces these errors. These errors are severe only for thermal infrared data acquired by NOAA-4.

2a.2.4 Estimation of Temperature Fields by Remote Sensing

To assess the accuracy of the temperature recorded in the thermal IR by the NOAA-3 and NOAA-4 satellites we have used temperature data from the National Weather Service, National Climatic Center, at a number of high quality, first order stations in California. The air temperature obtained at any station is fairly weakly correlated with sensed temperature. The water temperature data that we were able to use in our geographic area of interest was obtained at Lake Tahoe, Lake Oroville, Lake Berryessa, Suisun Bay, the Delta region and Folsom Lake. Using the temperature data of these bodies of water, we have done a preliminary determination of the correlation of satellite recorded temperature with ground truth. By extracting the satellite data pertinent to each station's data, and applying calibration procedures described above, we generated the 15 data points shown in Figure 1. In addition to the 6 stations mentioned earlier, we also made use of snow edge temperature which was assumed to be 0° C. Assuming that brightness is an indicator of snow, we used a particular count in a visible band to mask out nonsnow areas and display the temperature of the "snow" region in pseudo color as shown in Fig. 2. If the 0° level is also an indicator of snow, we can, in a particular count in the thermal band, mask out the domain above 0° C. We have done this over the "snow" domain of Fig. 2 and have obtained the psuedo color image shown in Figure 3; there is some discrepancy since the two figures do not coincide. The discrepancy appears around the edge of the "snow" region with the variation of the IR count of as much as 10 counts and thus a temperature variation of up to 5°C. Further study is underway to find reasons for this observed effect.

2a.2.5 Estimation of Snow Pack Albedo

Several questions are of interest in the use of remote sensing for the estimation of albedo. First, we note that the albedo is the fraction of incident energy reflected by the snow. Since satellite sensors measure the energy reflected in narrow spectral bands, it is not clear that any single band in the visible wavelength range or in the near-infrared is a good indicator of albedo. Some experimental results have been presented by O'Brien and Munis on the red and near-infrared spectral reflectance of snow (9). Their results indicate that the spectral reflectance scales down in a fairly uniform way across the wavelength range in the near-infrared but that this many not hold in the visible spectrum.

To proceed with a study of brightness values recorded by a satellite and their correlation with albedo values, we need ground truth on the albedo measured at ground stations.

To our knowledge, the only location in the Sierra Nevada where albedo is recorded is at the Central Sierra Snow Laboratory (CSSL) in Norden, California. The laboratory is in a clearing a few hundred feet wide in a forested area. Thus, the CSSL can be fairly precisely located on LANDSAT data but not on NOAA-3 and NOAA-4 images which have a resolution of 0.9km. A preliminary comparison of known albedo with the digital values recorded in the visible band by the NOAA-3 satellite indicate a very low correlation, if any, between the albedo and the recorded brightness. This lack of correlation may be due to the specifics of the location of the Central Sierra Snow Laboratory mentioned, with additional errors in obtaining the proper remote sensing data for the laboratory since geometric correction of the data is required. At this time, LANDSAT data are not available at suitable dates to allow the observation of curves such as shown in Figure 1. We are planning to use the infrequent LANDSAT data for a statistical correlation with albedo ground truth at CSSL. On the basis of the results of O'Brien and Munis (9), we expect that LANDSAT spectral band 7 may be a good indicator of albedo.

To pursue studies with NOAA-3 data in the visible range, we considered the evolution of albedo with time. Knowing that the albedo is generally quite high for new fallen snow and decreases fairly rapidly after a snow storm, we shall study the dynamic behavior of the counts in the visible band across the snow for a specific location for successive days. We shall mention the albedo curves based on a study made at the Central Sierra Snow Laboratory by the Corps of Engineers (6). These curves are shown in Figure 4. We also show in Figure 4 experimental values obtained at the Central Sierra Snow Laboratory during January 1975. The trend of the experimental curve matches well the standard curve proposed, but the absolute values are significantly in error.

Another possible use of remote sensing data in the study of albedo is to consider the spatial variation of reflectance across the snow pack as an indicator of variation in albedo. By analyzing the brightness values recorded by the NOAA-3 satellite in the visible spectrum we find in all cases that brightness covers a broad range of values across the snowpack. Since the reflectance of snow is similar for source-detector angles ranging from 0 to 30° (9), it seems that the variation in brightness in non-forested areas must be attributed mainly to differences in the evolution of snowpack with elevation, temperature, etc.

We shall proceed with our investigation by combining remote sensing data during the snow season with other data on relief and vegetation cover. Additional ground truth information on albedo is needed for continuation of our work.

2a.2.6 Monitoring the Areal Extent of the Snow

Within the context of our interest in developing data for a distributed model of snowpack evolution, this specific task is not of prime importance. We anticipate that instead of being a prime input to a model, the variation of areal extent with time will be used to check that the model is working satisfactorily. We have undertaken two investigations on areal extent determination. The first one is to compare the areal extent as determined from LANDSAT data to the same values obtained from a NOAA satellite's visible data. Results showing fairly close agreement between the values obtained from the two sources of data have been reported by Wiesnet and McGinnis (10). We are using classification algorithms and digital data rather than outlining the snowline images. We do not have yet enough comparable data from both satellite systems to derive definite conclusions.

Another related question is the determination of the snow areal extent on a daily basis (when possible) from NOAA satellite data. In particular, we are concerned with the snow areal extent of some watersheds. By mapping a watershed onto the NOAA image and determining snow and non-snow regions with appropriate geometric correction, we can compute the percentage of snow areal extent in that watershed. Since a number of data correction steps are needed in such a procedure, we shall generate a "noisy" time series for snow areal extent. Since we expect, on physical grounds, a smooth variation of snow areal extent with time we can use data filtering techniques to improve the estimate on any given date.

2a.3 DIGITAL IMAGE PROCESSING TECHNIQUES DEVELOPMENT

Our efforts in the specific technical field of digital processing have followed two parallel goals: to pursue vigorously the specific areas of work in which we feel we can make a valuable contritution and to incorporate into our facility and software the algorithms and techniques developed by others which seem to have most merit in applications.

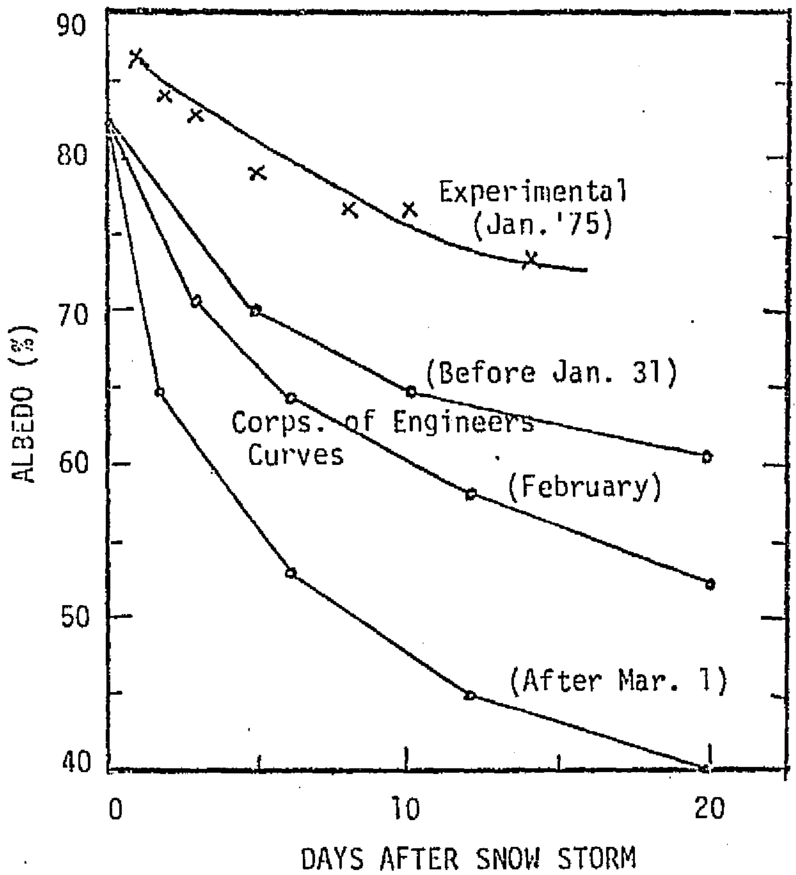

Figure 4: Evolution of Albedo

2a.3.1 Spectral-Spatial Combination of Multispectral Data

Because of the high correlation both spectrally and spatially in the LANDSAT-1 data, it seems possible to achieve at the same time, several of the following objectives.

1. Improvements of the quality of the data by reduction of the noise due to errors and coarse quantization.

2. Efficient representation of the data either for transmission (encoding) or for further processing. It appears probable that this capability can be achieved without any loss in, and possibly with a net improvement of, data quality.

3. Presentation of the information provided by sensors in a more interpretable form. This is related to our work in image enhancement.

4. Significant increase in the speed of processing for enhancement or classification. This capability depends upon the choice of linear combination with fast algorithms.

5. Utilization and combination of the data provided by several satellites. This area of work is of growing importance with the successive launches of new LANDSAT and meteorologic satellites. It is of specific importance to us because of our use of low resolution NOAA data for temperature information.

2a.3.2 Geometric Correction

We have implemented some single geometric correction algorithms. We are planning to assess the range of applications for which this level of correction is adequate. We are also working on some subpixel processing algorithms which bear on the problem of radiometric degradation resulting from sophisticated geometric correction of the data. Some preliminary algorithms are routinely used. Additional algorithms are being developed.

2a.3.3 Subpixel Processing

In some applications, notably the quantitative determination of water surfaces, it is desirable to incorporate subpixel information. For advanced geometric correction, it is also desirable to interpolate between pixels. A systematic approach to the design of efficient filters and algorithms for that problem has been undertaken by a Ph.D. student, Minsoo Suk, with partial support of the grant. A paper on basic design considerations has been published in the IEEE Transactions on Circuits and Systems (reprint is included as an appendix). Both fundamental and

applied work in this area will be continued. In particular, the work by May (11) presented at the 3rd ERTS Symposium, will be examined in the light of the fundamental limitations discussed in our work.

This work takes special significance in the applications (mentioned in Section III) which use low resolution data such as the NOAA satellites.

2a.3.4 Noise Removal

In our work with NOAA-3 and NOAA-4 we have encountered difficulties with the quality of the data. NOAA is quite concerned with this problem which limits the usefulness of the data, principally in the thermal infrared. Using our previous experience on noise stripping in the LANDSAT-1 satellite, we have been able to reduce this noise by digital processing. We have developed, in the past several years, a family of noise removal and data correction algorithms for satellite data. A comprehensive discussion and review of this work will be prepared for publication in the next year as time permits.

2a.4 PUBLICATIONS AND TECHNICAL PRESENTATIONS

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*M. Suk, K. Choi, V. R. Algazi, "Iterative Design of One and Two-Dimensional FIR Digital Filters", Proc. of the 1975 Asilomar Conf. on Circuits, Systems, and Computers.

*B. J. Fino and V. R. Algazi, "Computation of Transform Domain Covariance Matrices", Proc. of the IEEE, November 1975, pp. 1628-1629.

B. J. Fino and V. R. Algazi, "Unified Matrix Treatment of the Fast Walsh-Hadamard Transform", IEEE Trans. on Computers (In Press).

V. R. Algazi and M. Suk, "On the Frequency Weighted Least-Square Design of Finite Duration Filters", IEEE Trans. on Circuits and Systems, Vol. CAS-22, No. 12, December 1975, pp. 943-953.

*Reprints attached

WORK TIMETABLE

SEPTEMBER 1975 MAY 1976 MAY 1, 1977

INTERACTION WITH DWR	
SACRAMENTO RFC - SOIL MOISTURE	
SACRAMENTO RFC - SNOW MODEL	
EFFECT OF R, S, ON RFC MODEL	
LANDSAT - NOAA DATA USE FOR SNOW MODELS	1ST ORDER RESULTS — PHYSICAL MODELS
NASA - CORPS OF ENGINEERS AVST	

2a.5 REFERENCE AND DOCUMENT CONSULTED

1. Ambaruch, R., J. W. Simmons, "Developments in Applications of Remote Sensing to Hydrology Through Continuous Simulation", Remote Sensing of Earth Resources, Vol. II. Proc. of the 2nd Annual Remote Sensing Conference, Tullahoma, Tennessee, March 1973, pp. 1287-1306.

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3. D. R. Wiesnet, D. F. McGinnis, Jr., "Snow Extent Mapping and Lake Ice Studies Using ERTS-1 MSS Together with NOAA-2 VARR", Third ERTS Symposium, December 1973.

4. H. A. Odegaard, J. Skorve, "The Application of ERTS Imagery to Mapping Snow Cover in Norway", Final Report on ERTS-1 Contract F.418, May 1974.

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8. Stevenson, M. R. and F. R. Miller, "Application of Satellite Data to Study Oceanic Fronts in the Eastern Pacific": Inter-American Tropical Tuna Commission, La Jolla, California, Final Report Grant No. 04-3-158-59, May 1974.

9. O'Brien, H. W., and R. H. Munis, "Red and Near-Infrared Spectral Reflectance of Snow". Research Report 332, Cold Regions Research and Engineering Laboratory, Hanover, N. H., March 1975.

10. D. R. Wiesnet, D. F. McGinnis, Jr., "Snow Extent Mapping and Lake Ice Studies Using ERTS-1 MMS Together with NOAA-2 V RR", Third ERTS Symposium, December 1973.

11. May, C. L., "ERTS Image Data Compression Technique Evaluation", Proc. 3rd ERTS Symposium, December 1973, paper I9, pp. 1823-1836.

Watershed Model. The work of Ambaruch and Simmons suggested that a quantitative assessment of the potential of remote sensing inputs of a watershed model should begin with a study of the sensitivity of the model to inputs and parameters. Although hydrologists have, from experience, a good feeling for the importance of various parameters, a quantitative sensitivity analysis would be of significant interest.

We proceeded with an analysis of the Sacramento River Forecast Center (RFC) hydrologic model and it became quickly apparent that such work cannot be carried out analytically. The reason for this is that hydrologic models such as the Sacramento RFC model are only partly analytical. Some of the parameters are actually determined by computer optimization during a calibration phase. This type of optimization consists of the computer determination of unknown parameters of a model so that the output of the model approximates physical outputs in an optimum fashion, according to some objective function or approximation measure.

Since May 1975, we have implemented the Sacramento RFC hydrologic model on the Davis computers. This model has been made available to us by Burnash and Ferral, Hydrologists with the Sacramento RFC, who developed the model and have been using it for several watersheds in California.

The Sacramento RFC model consists of a main program, also called the soil moisture model and a snow submodel which generates equivalent precipitation for the snowmelt, which is used in the main program. We have implemented the soil moisture program and have available historic data from 1962-69 for the middle fork of the Feather River.

Keeping in mind that our ultimate objective is to determine the use in this hydrologic model of parameters acquired by satellite remote sensing, the specific objectives of our work are as follows:

1. Analysis of the model: To achieve, by simulation and analytic study, some insight into the behavior of the hydrologic model. Generally, this results in a simplified description of the behavior of the model under specific climatic or seasonal conditions.

2. Sensitivity Study: To study the effect of changes in the dynamic inputs and model parameters on the runoff forecasted by the model. By focusing specifically on parameters which may be determined by remote sensing, to provide critical information on the parameters to be measured, their expected effect on the forecast, and the time at which they should be measured.

3. Simulation: To use parameters actually acquired by remote sensing in the operational model and to observe the exact effect that these new acquisition techniques have on the runoff forecasted. Parts 1 and 2 above are nearly completed for the soil moisture model.

TABLE 1. SUMMARY OF SENSITIVITY*, (MONTHLY RUNOFF)

MODEL REGIME

PARAMETER	FALL	WINTER	SPRING	SUMMER
ED	≤ .2	≤ .2	≤ .65 CARRY OVER	≤ .2 CARRY OVER UP TO 6 MONTHS
PCPT	AS HIGH AS 4, CARRY OVER, FUNCTION OF RAINFALL	INTERMEDIATE BETWEEN FALL AND SPRING	1. INDEPENDENT OF RAINFALL	N.A.
LZTWM	≤ .2 FUNCTION OF RAINFALL	≤ .1	≤ .3	≤ .5
UZTWM	HIGHEST IN NOV. ≤ 1.8 FUNCT. OF RAINFALL	USUALLY _ 1.	≤ .15	≤ .5
PCTIM	≤ .4	≤ .15	≤ .1	≤ .1
SARVA	≤ .15	≤ .025	≤ .025	≤ .4

$$\text{*SENSITIVITY, } S = \frac{\%\ \text{CHANGE IN OUTPUT}}{\%\ \text{CHANGE IN PARAMETER}}$$

APPENDIX A: SENSITIVITY ANALYSIS OF THE SACRAMENTO RFC MODEL

In accordance with the agreement between personnel of the University of California who are funded under the NASA Grant and Mr. Burnash of the National Weather Service in Sacramento on the use of the River Forecast model, we have been able to implement this model on the compus computer at Davis.

The purpose of our work with the Sacramento RFC model was twofold.

1. To study the sensitivity of the model to the primary parameters of the model for the specific conditions which exist in the Sierra Nevada.

2. To simulate the effect of parameters estimated by Remote Sensing on the operation of the model.

The interest of sensitivity analysis in hydrologic modeling is well documented and is of use in all phases of the modeling process: model formation, model calibration and model verification. Our objective was to rank variables and parameters in an order of relative importance, based on the intended hydrologic use of the model.

The RFC model consists of a soil moisture model and a snow submodel. At this time, the main program of the soil moisture model for the Middle Fork of the Feather River has been implemented on the campus computer. We are using in our study the 8 years of historical records on precipitation and runoff available for that watershed.

I. DESCRIPTION OF THE MODEL - MODEL DYNAMICS

A description of the Sacramento RFC hydrologic model has been written by Burnash, Ferral and McGuire [1] . As we proceed in our analysis of this model we need a quantitative assessment of the dynamics of the model to guide the choice of suitable simplifications and approximations and the interpretation of the results obtained. We shall thus give an overview of the RFC hydrologic model borrowing key elements from available documents. Based on this brief overview and on our experience with the operation of the model, we will then comment on the "time constants" of each part of the model. These time constants indicate how rapidly we expect parts of the model to respond to changes in precipitation and in other seasonal effects.

Physical Elements of a Watershed: Rainfall occurring over the basin is considered as falling on two basic areas: 1) A permeable portion of the soil mantle, 2) a portion of the mantle covered by streams, lakes, etc., and other impervious material directly linked to the stream flow network. The permeable area produces runoff when the rainfall rate is heavy enough, while the impervious area produces runoff from any rain. For the middle fork of the Feather River the impervious area represents about 2% of the basin. The permeable portion of the basin is visualized as consisting of an upper and a lower zone. The upper zone is in turn modeled by two water storage bins, one accounting for water bound to soil particles and

intercepted by plants and trees, and one accounting for the storage of free water. The first of these bins contains what is called the upper zone tension water (UZTW), and it must be completely full before any water can seep through to any of the other water storages. The water stored in this bin contributes to evapotranspiration, and therefore has a time constant which depends on the time of the year; for a spring month, this constant is of around one month.

Once the upper zone tension water requirements have been met, any excess water is directed to the second storage compartment; the water stored here is free to move, and does so, producing interflow (lateral movement) and percolation (downward), with percolation accounting for most of the use of the upper zone tension water.

Percolation, the mechanism by which water from the upper zone is transferred to the lower zone, is very much a function of the moisture in the soil, and so the rate at which it takes place can vary widely, making the time constant of water stored as free water in the upper zone range anywhere from about 1 hour to a day.

The lower zone consists of 3 water storages; the first of these stores tension water which is used for transpiration purposes only, and has as a result a time constant of approximately 3 months in the spring.

In contrast with the upper zone, a portion of the percolated water is stored as free water even if the lower zone tension water requirements have not been met. Once those requirements are met, all excess percolated water is assigned to the two free water storages; these two storages fill up at different rates depending on the particular water needs of each of them and drain at considerably different rates giving rise to baseflow, thus accounting for the recession portion of the hydrograph.

Time constant for the supplementary free water storage is approximately 10 days, and for primary water storage is about 4 months. Primary water storage provides almost the entire streamflow during the summer.

A very small fraction of the free water stored in the lower zone is lost in the form of subsurface overflow.

For a given day, the sum of all runoff components except base flow is processed by the unitgraph (with appropriate initial conditions), and the result of this is added to the base flow component. This essentially, except for a very small loss term due to water evaporated from that fraction of the basin covered by water, is what constitutes the streamflow for the day.

Figure A-1 taken from [1] shows a diagram of the parts of the model that we have just described.

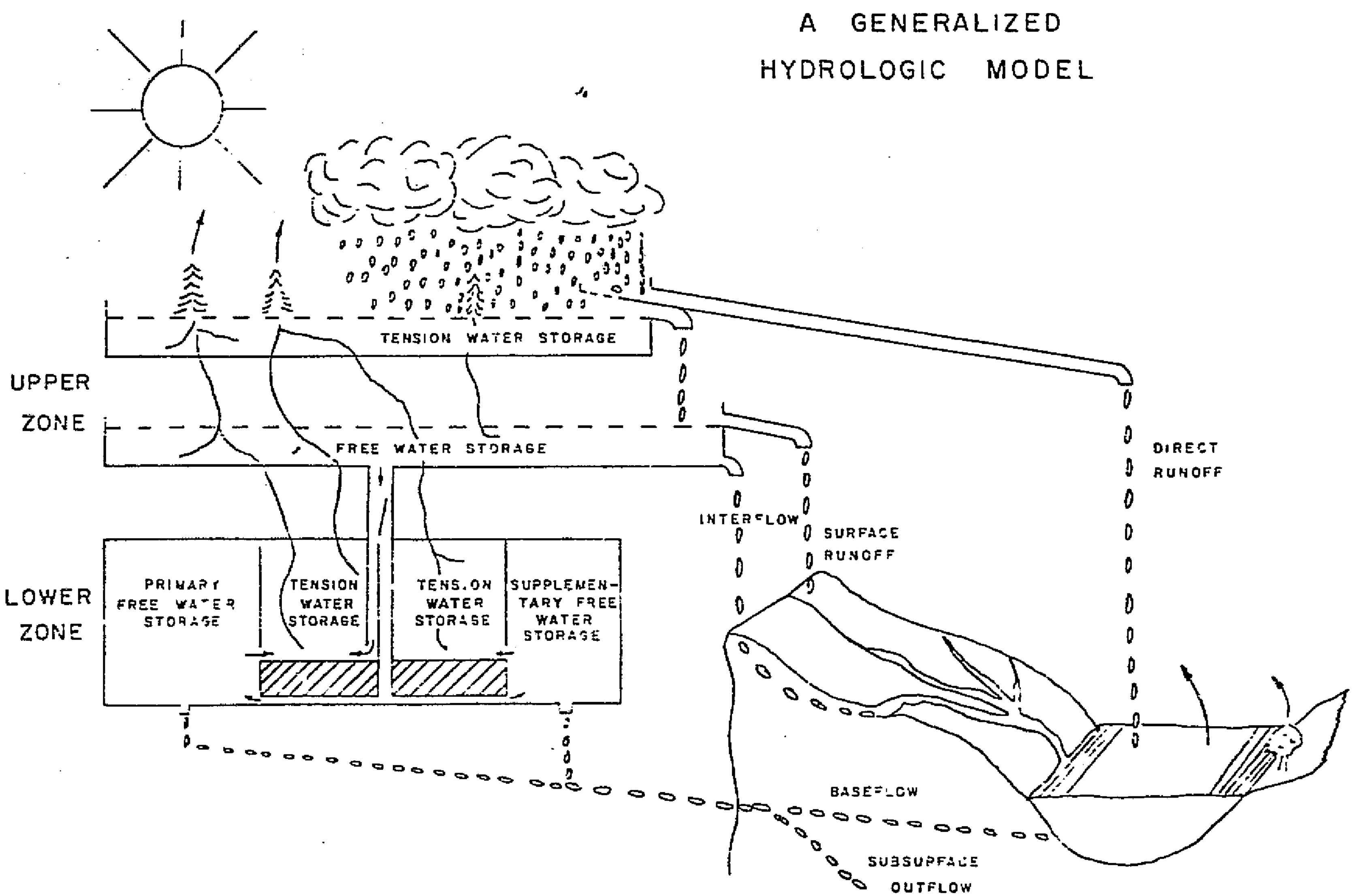

A GENERALIZED
HYDROLOGIC MODEL
TENSION WATER STORAGE
UPPER
ZONE
FREE WATER STORAGE
LOWER
ZONE
PRIMARY
FREE WATER
STORAGE
TENSION
WATER
STORAGE
TENSION
WATER
STORAGE
SUPPLEMENTARY FREE
WATER
STORAGE
INTERFLOW
SURFACE
RUNOFF
DIRECT
RUNOFF
BASEFLOW
SUBSURFACE
OUTFLOW

Figure A-1

II. PARAMETERS OF THE MODEL

A quantitative analysis of the hydrologic model represented in Figure A-1 requires the knowledge of the parameters of the model. In order to specify the model a basin or subbasin is modeled as spatially lumped. Thus, for instance, the upper zone tension water storage of a basin is characterized by two numbers, its capacity, i.e. the maximum water content possible, and the actual water content in upper zone tension water. Calibration of the model requires determination of the capacity (a characteristic of the watershed) and in operation the model updates the content daily. Most other parameters may also be classified either as model parameters, which are characteristic of the watershed and which are determined once and for all in a calibration phase, and as dynamic parameters, which are either measured or estimated or computed and updated internally during the operation of the hydrologic model. Most parameters used in the Sacramento RFC model are defined in Table 1. They can be classified as follows:

Model Parameters (characterize the watershed)

1. (unit hydrograph, SARVA, PCTIM)

2. Capacities: UZTWM UZFWM

   LZTWM LZFWPM LZFWSM

Dynamic Parameters (daily or seasonal change)

1. EVAPT: Evapotranspiration Potential (monthly estimate)

2. Contents: (Daily Update) UZTWC UZFWC

   LZTWC LZFWPC LZTWSC

Inputs: Precip. (5 stations) (Daily, in the form of rain or snowmelt)

Outputs: Daily Runoff

The determination of the model parameters is done in a calibration phase, which requires currently many years of detailed historical record. Thus a possible application for remote sensing is to provide an alternate methodology for a convenient determination of these model parameters. However, in the operational use of the hydrologic model, the model parameters have been determined. Thus only the dynamic parameters and the inputs can be used to modify the daily runoff forecast by the model.

We show, in Figure A-2, a typical output of the hydrologic model obtained during the calibration period. We observe some discrepancy between the observed runoff of the middle fork of the Feather River and the runoff forecasted by the model.

Table 1: Definition of symbols used in the RFC Hydrologic Model

1. Upperzone tension water
   a) UZTWM, maximum capacity in inches
   b) UZTWC, contents in inches
2. Upper zone free water
   a) UZFWM, maximum capacity in inches
   b) UZFWC, contents in inches
   c) UZK, lateral drainage rate
3. The percolation rate from upper zone free water into the lower zone
   a) PBASE, the through-put rate during saturated conditions
   b) Z, the proportional increase in percolation from saturated to dry conditions
   c) REXP, an exponent determining the rate of change of the percolation rate with changing lower zone water contents
4. Lower zone tension water
   a) LZTWM, maximum capacity in inches
   b) LZTWC, contents in inches
5. Lower zone free water
   a) Supplemental free water storage
      1) LZFSM, maximum capacity in inches
      2) LZFSC, contents in inches
      3) LZSK, lateral draining rate
   b) Primary free water storage
      1) LZFPM, maximum capacity in inches
      2) LZFPC, contents in inches
      3) LZPK, lateral drainage rate
   c) PFREE, direct percolation to Lower Zone Free Water
   d) Ground water discharge not observable in the river channel
      1) SIDE, ratio of non-channel subsurface outflow to channel baseflow
      2) SSOUT, discharge required by channel underflow
   e) RSERV, fraction of lower zone free water incapable of resupplying lower zone tension

III. SENSITIVITY ANALYSIS - GENERAL DISCUSSION

A. Basic Considerations

Let Y be an output variable which depends on input x and a set of parameters $\{a,b,c\}$. Then the sensitivity of Y to parameter a, for $x=x_0$, $a=a_0$, $b=b_0$, $c=c_0$ is given by

$$\frac{\Delta y}{\Delta a} = \frac{Y(X_0;a_0+\quad a,b_0,c_0) - Y(x_0;a_0,b_0,c_0)}{\Delta a}$$

s, the relative sensitivity, also of general interest, is given by

$$S_a \triangleq \frac{\Delta Y/Y}{\Delta a/a_0}$$

For small $\frac{\Delta a}{a_0}$ we have approximately $S_a = [\partial Y/\partial a]/[Y/a]$

If there are uncontrolled parameters which affect Y, or if for some other reason, the relation between Y and x and a,b,c is random, then Δ Y as above, will be a random variable. We may then consider the statistical characteristics of Y, such as its sample mean, sample variance, range, histogram, to characterize the sensitivity.

In so far as possible we have tried to avoid the use of statistics in the study of the sensitivity of the model. To a large extent we have succeeded in doing so by consideration of different seasonal regimes for the model. This breakdown into seasonal regimes is physically meaningful in California since there are well marked seasonal weather patterns. It leads mathematically to significant simplifications in the operation of the model and simpler, deterministic relations in the sensitivity analysis.

B. Seasonal Regimes

There are two very well marked regimes for the Middle Fork of the Feather River. The summer regime, characterized by an almost complete lack of precipitation and by the fact that the upper zone tension water content (UZTWC) is small. Quantitatively, we use UZTWC   .1 and PCT ___ 0 and find that such a regime holds during the following months.

MIDDLE FORK FEATHER RIVER AT MERRIMAC   DRAINAGE AREA 1078.0 SQ.MI.

UNIT HYDROGRAPH 0.760 0.155 0.085
RAINFALL STATIONS AND WEIGHTS 1 0.226 2 0.030 3 0.216 4 0.247 5 0.123

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
PAN EVAP	0.01	0.03	0.05	0.06	0.07	0.07	0.17	0.22	0.17	0.06	0.02	0.02
WEIGHTS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
EVAP	0.01	0.03	0.05	0.06	0.07	0.07	0.17	0.22	0.17	0.06	0.02	0.02

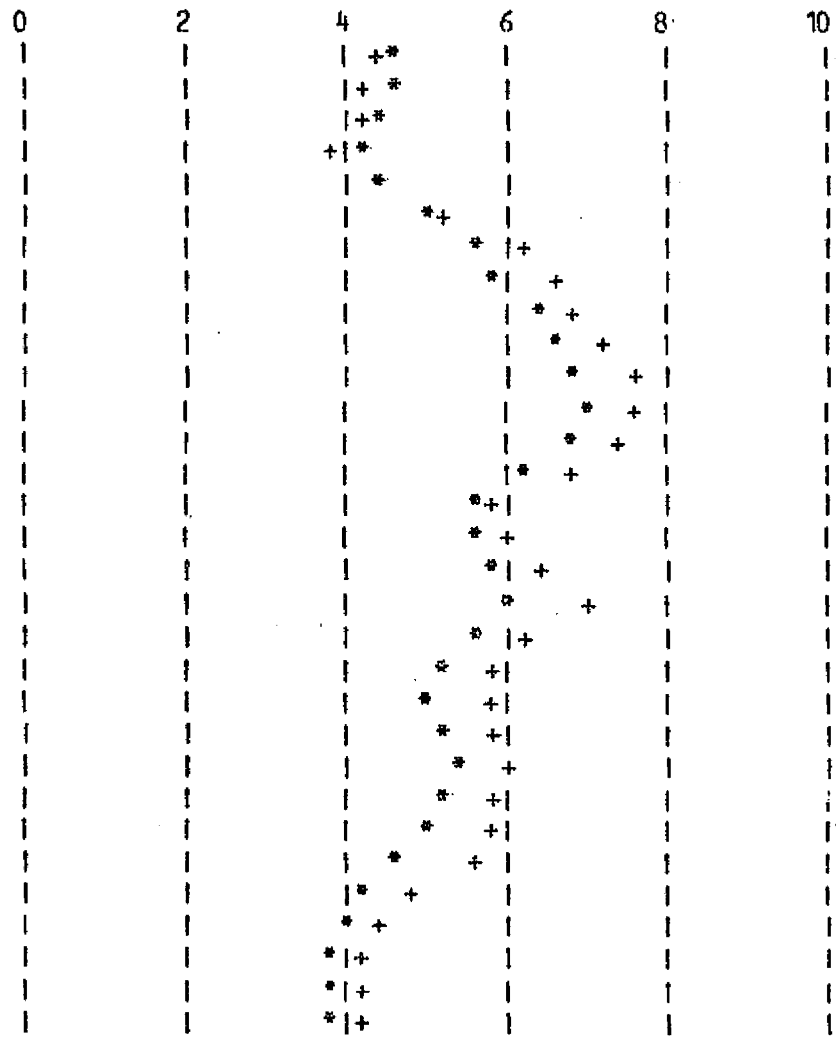
5 69

	UZTW	UZFW	LZTW	LZFWS	LZFWP
CAPACITY	4.700	2.220	10.500	7.170	8.715
CONTENTS	4.700	0.250	10.500	0.835	4.304

UZ-K	LZS-K	LZP-K	ZPERC	REXP	SIDE	SSOUT	PCTIM
0.217	0.099	0.0080	21.500	4.800	0.160	0.000	0.020

SARVA	RSERV	IMPRT	PBASE	ADIMP	ADIMC	PFREE
0.008	0.340	0.000	0.780	0.028	15.200	0.200

DAY	PCP	CFS/SQ.MI. OBS	FCST
1	0.32	4.680	4.387
2	0.24	4.560	4.230
3	0.24	4.504	4.293
4	0.11	4.217	3.854
5	0.35	4.328	4.440
6	0.47	4.986	5.266
7	0.52	5.534	6.185
8	0.45	5.831	6.578
9	0.43	6.471	6.730
10	0.54	6.693	7.238
11	0.50	6.758	7.507
12	0.45	6.907	7.560
13	0.41	6.730	7.420
14	0.29	6.285	6.835
15	0.21	5.682	5.787
16	0.34	5.580	5.990
17	0.43	5.719	6.437
18	0.47	5.942	6.964
19	0.27	5.571	6.238
20	0.23	5.200	5.736
21	0.28	4.922	5.794
22	0.31	5.107	5.774
23	0.35	5.385	5.920
24	0.31	5.293	5.875
25	0.29	5.014	5.751
26	0.28	4.643	5.599
27	0.19	4.272	4.843
28	0.18	3.994	4.497
29	0.18	3.762	4.230
30	0.22	3.864	4.140
31	0.21	3.892	4.119



MONTHY TOTALS IN INCHES

RAIN	MELT	E-DEMAND	E-USED	SURFACE LOSS	COMPUTED RUNOFF	OBS RUNOFF
10.07		2.17	2.14	0.02	6.55	6.03

MONTHLY WATER BALANCE ERROR = 0.52 IN.

ANNUAL TOTALS
AVAILABLE WATER E-DEMAND E-USED COMPUTED RUNOFF OBSERVED RUNOFF

Figure A-2

Summer Regime

Year	Start	End
1962	July	September
1963	July	September
1964	July	October
1965	July	October
1966	June	October
1967	August	October
1968	June	September

This summer model can tolerate some rain, as long as the rain is not sufficient to fill up the upper zone tension water significantly.

Under the mathematical conditions stated the hydrologic model becomes extremely simple.

Another physically meaningful set of conditions obtains whenever both upper zone and lower zone tension water storage bins are full, or UZTWC=UZTWM and LZTWC=LZTWM. This type of behavior occurs during the late winter and early spring months (we shall call it the Spring Regime) when precipitation occurs essentially every day, so that the upper zone tension water is replenished everyday. The lower zone tension water also fills and remains filled in good part because of a very long depletion time constant of several months. For the years 1962 through 1968 the starting and ending month of the Spring Regime are as follows:

Spring Regime

Year	Start	End
1962	March	May
1963	February	May
1964	March	May
1965	February	May
1966	March	April
1967	February	June
1968	March	May

Under these conditions, again the behavior of the model simplifies greatly and allows fairly definite statements as to the sensitivity of the model to parameter and inputs. During the intervening season, that we shall call Winter and Fall Regimes, the behavior of the model is more complex and we will need, in some cases, to rely on statistical characterizations of the sensitivity.

C. Input and Output Variables and Parameters of This Study

In our study of the Sacramento RFC hydrologic model, we have given consideration to several performance indices, corresponding to distinct interpretation of the output variable Y in the general discussion of sensitivity. These performance indices are intended to match the various uses of the model for forecasting purposes. Since the basic output of the model is the daily basin runoff in cubic feet per second per square mile (CFS/SQ.MI.) all performance indices are based on that model output

sequence. We have considered the peak daily runoff and the storm volumetric runoff. These two performance indices are used to assess the performance and sensitivity of the model in near term forecasting. Some fairly definite results have been obtained for the daily peak flow, but the storm volumetric runoff is difficult to define and to handle and more work will be needed. We also consider the monthly volumetric runoff which is used in seasonal runoff forecasting and the daily baseflow which is of interest during the summer months.

We have considered the sensitivity of the Sacramento RFC hydrologic model to the primary dynamic parameters and inputs, Evapotranspiration (ED) and Precipitation (PCPT), which include the effects of both rainfall and snowmelt. We have also considered the sensitivity of the model to the model parameters: Upper Zone Tension Water Capacity (UZTWM), Lower Zone Tension Water Capacity (LZTWM), Impervious Area (PCTIM) and area of streams, lakes, and riparian vegetation (SARVA).

Some broad results as to the sensitivity of the monthly runoff of each of the parameters under study and for each of the seasonal regimes discussed are given in Table 2.

Following, we give a more detailed discussion of the results of our sensitivity analysis for Evapotranspiration and Precipitation and the other model parameters of our study.

IV. EVAPOTRANSPIRATION

i) Physical Basis

Evapotranspiration is defined as the combined effect of "transpiration from leaf surfaces of water taken from the soil by plant roots, direct evaporation from the soil and from leaf and other surfaces wetted by rain and direct evaporation from the surfaces of lakes, ponds, and streams". Transpiration is usually the dominant process. The process of evapotranspiration is difficult to measure and this uncertainty contributes significantly to simulation error.

A measure of the evapotranspiration requirements of the basin is given by the evapotranspiration demand (ED), which is defined to be "that evapotranspiration which would occur if there were no deficiencies in the availability of moisture for evapotranspiration by that area's particular plant regime".

Evapotranspiration from the area covered by surface water or phreatophyte vegetation is computed at the potential rate, i.e.,

$$EVAPT = ED \times SARVA.$$

Moisture is also extracted from the upper zone at the potential rate multiplied by the ratio of UZTWC to UZTWM.

In the lower zone, evapotranspiration takes place at a rate determined by the unmet evapotranspiration demand times the ratio of LZTWC to LZTWM.

MODEL REGIME

PARAMETER	FALL	WINTER	SPRING	SUMMER
ED	≤ .2	≤ .2	≤ .65 CARRY OVER	≤ .2 CARRY OVER UP TO 6 MONTHS
PCPT	AS HIGH AS 4, CARRY OVER. FUNCTION OF RAINFALL	INTERMEDIATE BETWEEN FALL AND SPRING	1. INDEPENDENT OF RAINFALL	N.A.
LZTWM	≤ 2 FUNCTION OF RAINFALL	≤ 1.	≤ .3	≤ .5
UZTWM	HIGHEST IN NOV. ≤ 1.8 FUNCT. OF RAINFALL	USUALLY ≤ 1.	≤ .15	≤ .5
PCTIM	≤ .4	≤ .15	≤ .1	≤ .1
SARVA	≤ .15	≤ .025	≤ .025	≤ .4

SUMMARY DISCUSSION OF SENSITIVITY. MONTHLY RUNOFF.

$$\text{SENSITIVITY } S = \frac{\%\text{ CHANGE IN OUTPUT}}{\%\text{ CHANGE IN PARAMETER}}$$

TABLE 2

The sum of these three components is the total amount of water that the basin loses due to evapotranspiration.

Since evapotranspiration demand (ED) along with the state of the system determines the quantitative effect of the evapotranspiration mechanism, we have systematically studied the sensitivity of the model to the parameter ED.

ii) Nominal Values

Evapotranspiration is a seasonal effect; a graph of ED vs. time of the year looks approximately bell shaped. For the Middle Fork Feather River, the graph peaks in August with a value of ED of .220 (in/day), the lowest value occurring in January at .015 in/day.

iii) Effect of ED on Monthly Runoff

A. Summer

During this time of the year, sensitivity to evapotranspiration is low, even though ED is at its highest. This is because, in the summer, most of the flow comes from baseflow, which is not affected by evapotranspiration. Loss of flow during the summer comes about as a result of surface loss through SARVA (See Table 2 for sensitivity). However, under certain conditions, such as low rainfall in the following Winter, a 40% change in ED can give rise to as much as a 50% change in runoff 5 or 6 months later. This is because changing ED leads to a change in LZTWC, and this in turn has an effect when the LZTW storage compartment fills up later on.

B. Fall

During the early portion of the season, sensitivity is low because the model is still operating in the summer mode. During the second half of the fall the value of ED drops considerably so that the amount of evapotranspiration water is reduced, thus making its effect less critical on model behavior. (See Table 2 for value of sensitivity).

C. Winter

For this regime, the effect is still low because ED is low and runoff is fairly high. Towards the end of this regime, however, the value of ED begins to come up again, thereby increasing the sensitivity. With available data, the highest sensitivity for this season is .5, but generally the sensitivity stays below .25. (See Figures A-3, A-4, and A-5).

D. Spring

During this time of the year sensitivity, and a functional relationship can be derived because, on a monthly basis, the model can be approximately described by:

$$\text{runoff} \simeq K \times \text{rainfall} \qquad \text{K is a constant} \qquad (1)$$

$$\text{from (1), } \%\ \Delta\ \text{runoff} \simeq \%\ \Delta\ \text{rainfall} \qquad (2)$$

changing ED is almost equivalent to changing the amount of rainfall since the UZTW storage is full, so that

$$\%\ \Delta\ \text{rain} = \frac{\%\Delta\ \text{ED} \times \text{ED}}{\text{rain}} \qquad (3)$$

Substituting (3) in (2) and using (1),

$$\%\Delta\ \text{runoff} = \frac{\text{ED} \times \text{ED} \times K}{\text{runoff}} \qquad (4)$$

For a given % ED, this equation describes a hyperbola if ED is constant. This is true of May, April, and June. In June, however, the model can no longer be described by (1) and so (4) breaks down. For months in which ED is not constant, an average value of ED is substituted so that (4) will still hold, as long as (1) holds. Such is the case for February and March.

Residual Effect in Spring

A change in ED for a given month will not only have an effect on that month's runoff, but will also influence the output of the system in subsequent months, by changing the state of the system at the beginning of the next months.

This will of course always happen independently of when ED is perturbed. This effect, however, will be more noticeable for a change in the spring, because of higher sensitivity during this season, and because subsequent months are generally of lower runoff (water is receding) making any perturbations stand out.

Computer runs show that there is a strong relationship between the first month's runoff change and the second month's runoff change as a result of a change in the first month's ED (Figure A-6). The right portion of the curve is to be expected on the basis of the previous paragraph. The left side appears to reflect the fact that, for a low amount of rain, the system falls out of the winter regime and begins to exhibit fall type behavior.

This effect is not limited to the second month, but it gradually decreases as time progresses, i.e., in subsequent months. For other seasonal regimes the residual effect has a sensitivity of less than .3.

Linearity of Cumulative Effect

The effect of two separate changes in ED is additive in a simple linear fashion for the spring season, for monthly and peak runoff.

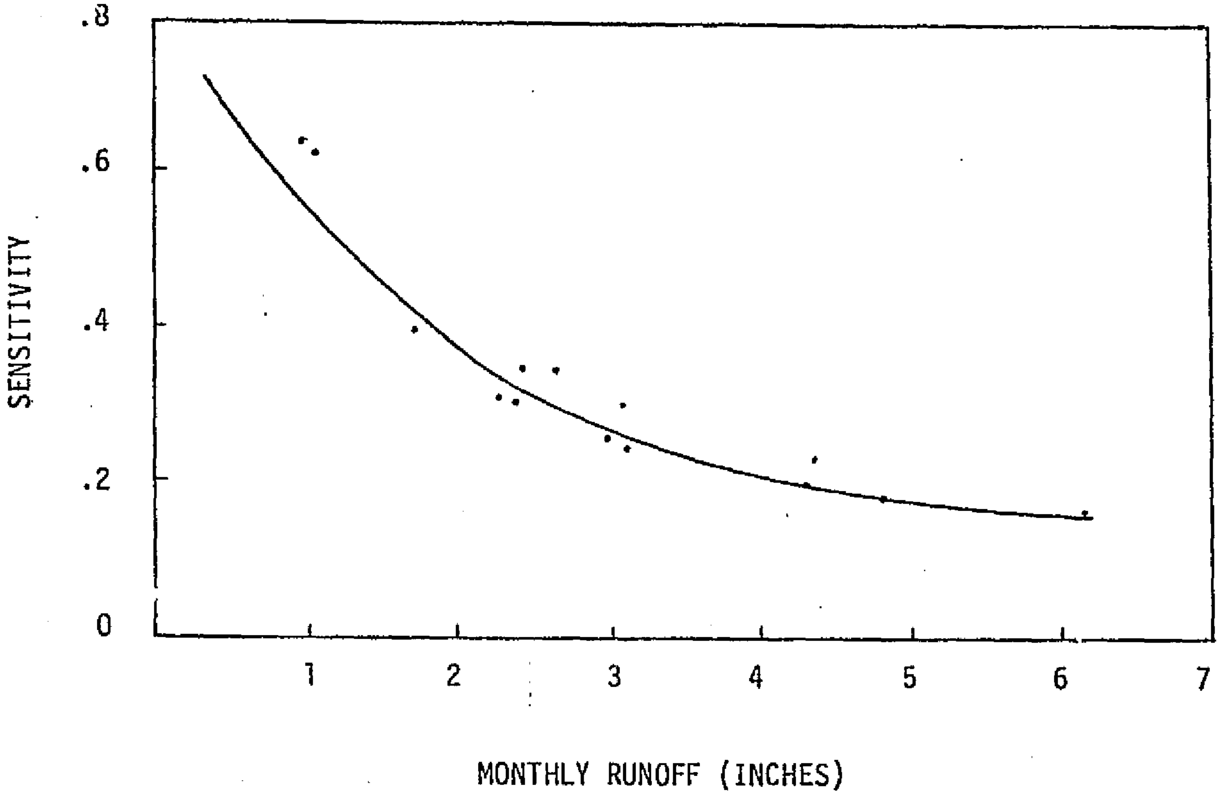


Figure A-3: Monthly runoff sensitivity to ED for April and May

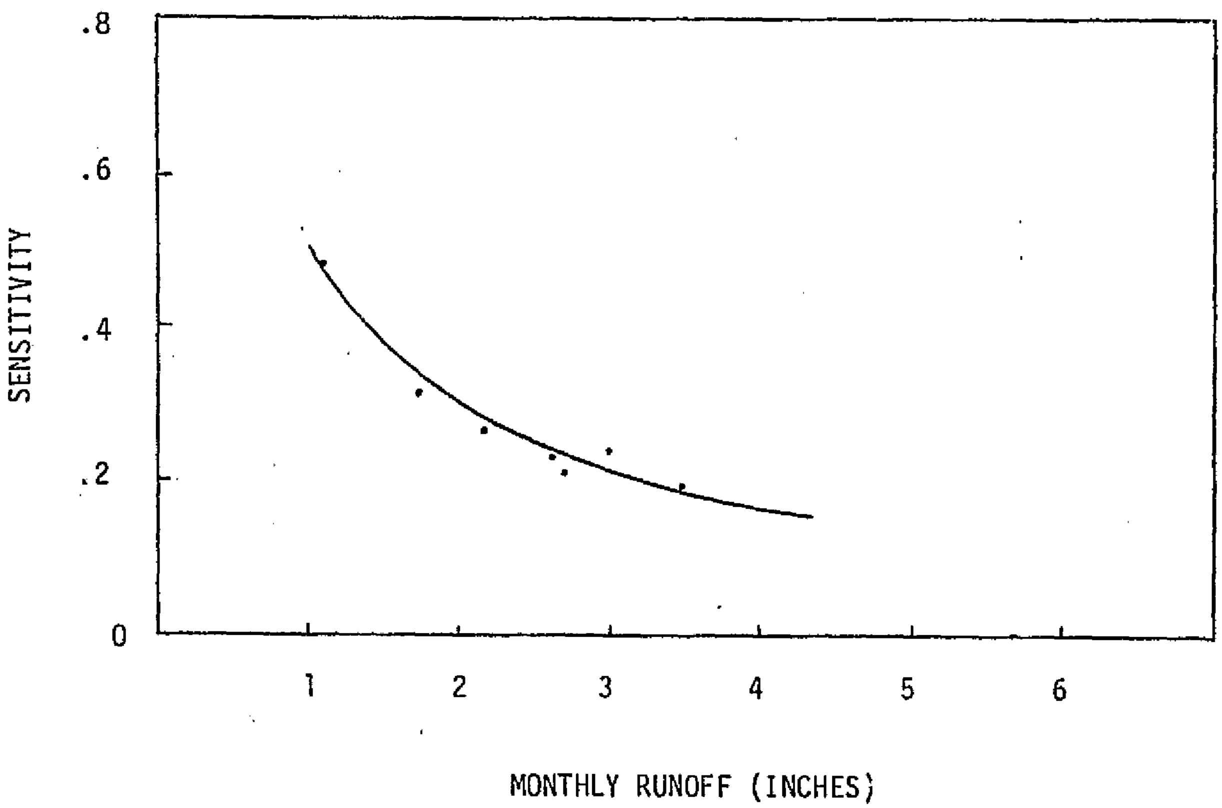


Figure A-4: Monthly runoff sensitivity to ED for March

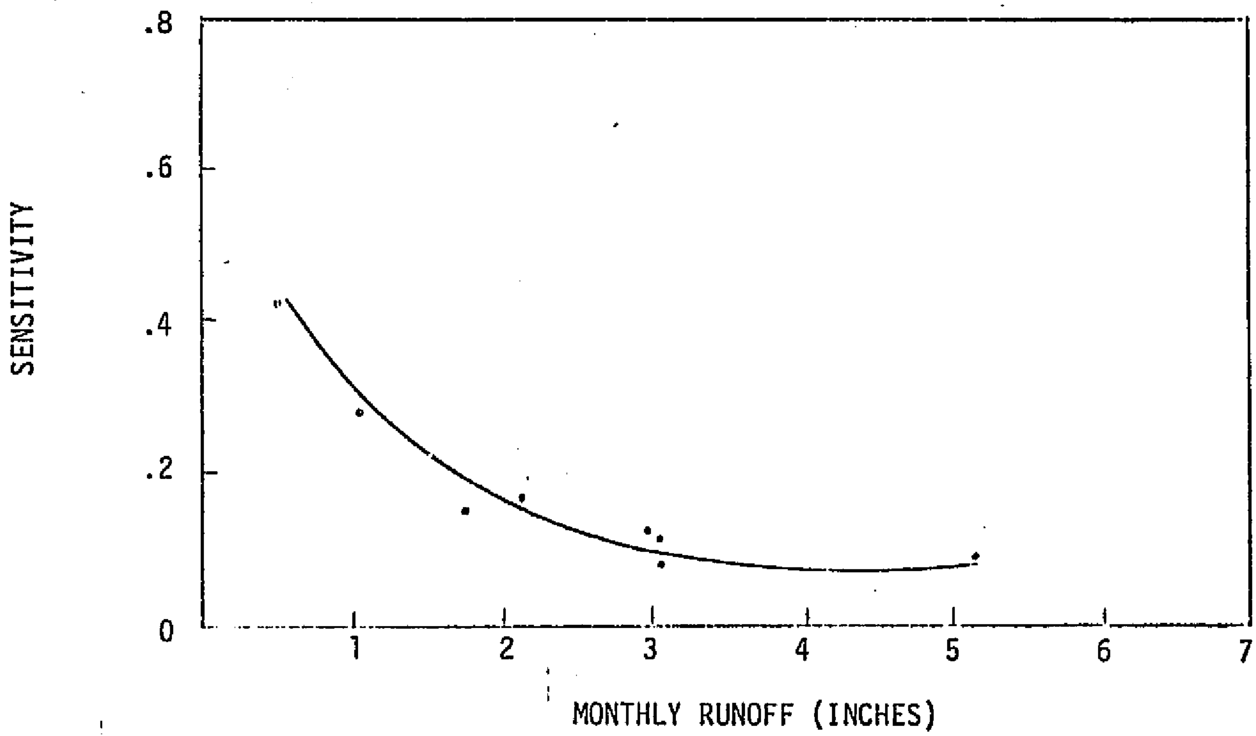


Figure A-5: Monthly runoff sensitivity to ED for February

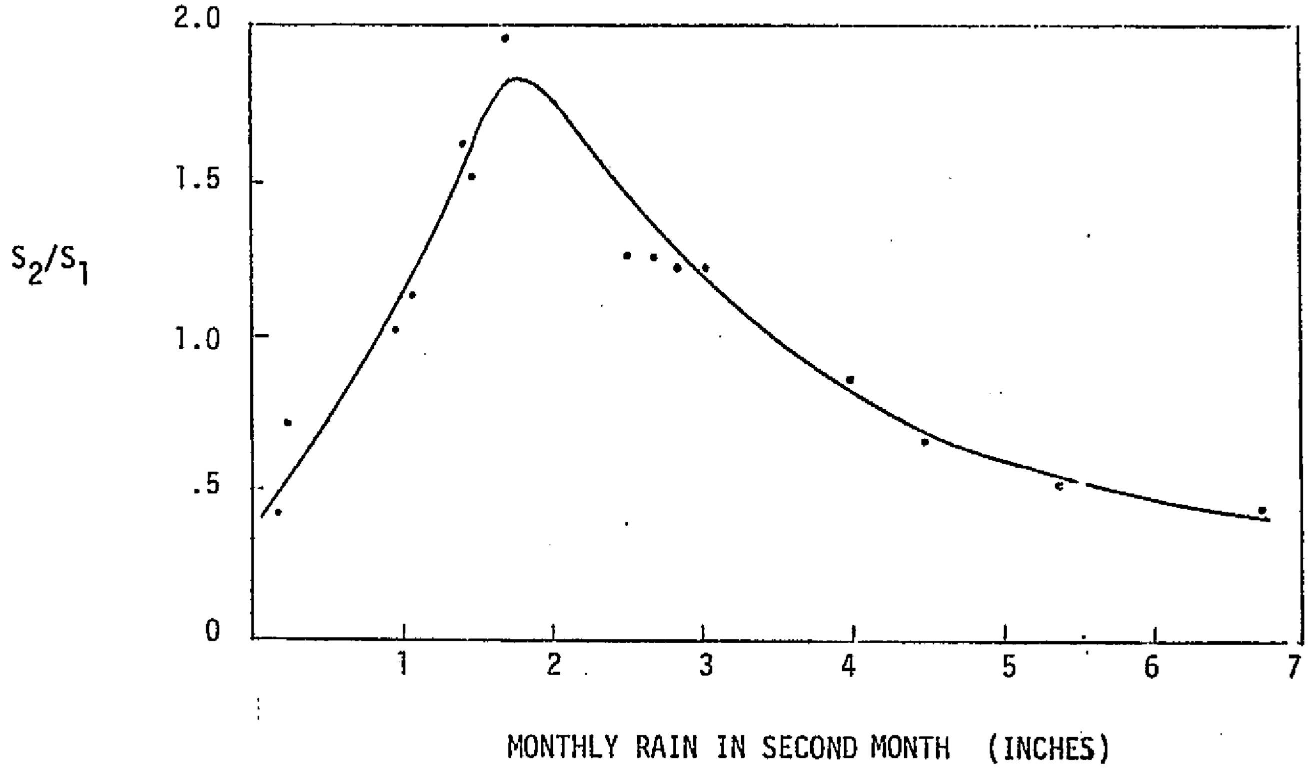


Figure A-6: Residual effect of ED on second month runoff

S_2/S_1 ratio of 2nd and 1st month sensitivities to ED

iv) Effect of ED on Low Flow

Low Flow is taken to be the average flow on four consecutive days in summer which indicate the lowest flow of the year. Changes in low flow can occur as a result of changing ED in either the spring or the summer.

The spring perturbation will in general yield low sensitivities, typically less than .25. Under certain circumstances this number can go up to .5. This will happen for very dry years, in which FSWC is low. Since this water storage determines the long term component of base flow, a low value for it leads to higher sensitivities in summer flow.

v) Effect of ED on Peak Flow

Because of the random nature of the this parameter (as to where in the month the peak flow will be located), only statistical data are available.

Spring: Figure A-7 shows a histogram of sensitivity for April and May. On this basis, one can state that on the average, 95% of the cases will exhibit sensitivities of less than .37. Similarly, for the residual effect on subsequent months, 90% of the cases will have sensitivities of less than .8. The higher value of sensitivity for the second month can be related to Figure A-6 in which it is seen that, past a certain threshold, the sensitivity to the residual effect is inversely proportional to the runoff in the second month.

Winter: Typically the sensitivity is less than .3. However, months for which the amount of rain is low, the peak flow is low, and the peak day occurs late in the month, will tend to show sensitivities which can be 3 or 4 times higher than normal.

Summer and Fall: Sensitivity is low; typically less than .3.

vi) Effect on Storm Runoff

No data yet.

V. PRECIPITATION

i) Physical Basis

The water balance characterization of the system makes it desirable that the precipitation estimate be as true as possible. Rain information for the basin is only known on a pointwise basis so that an averaging procedure in which weights are assigned to each one of these points is used to determine the total amount of precipitation for the basin.

This averaging procedure is somewhat prone to errors. In addition to this, given that the system is non-linear, averaging the inputs leads to a different analysis than if individual inputs had been used and the results combined.

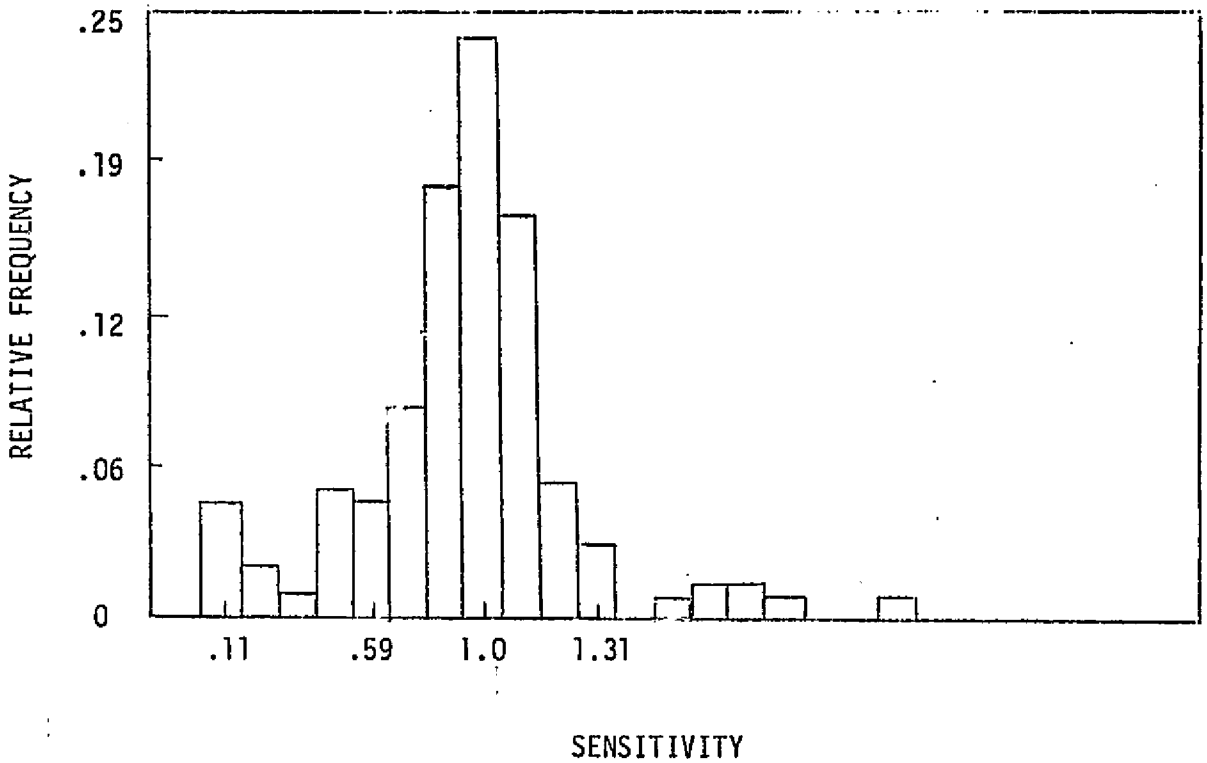


Figure A-10: Histgram of peak flow sensitivity to precipitation for April and May

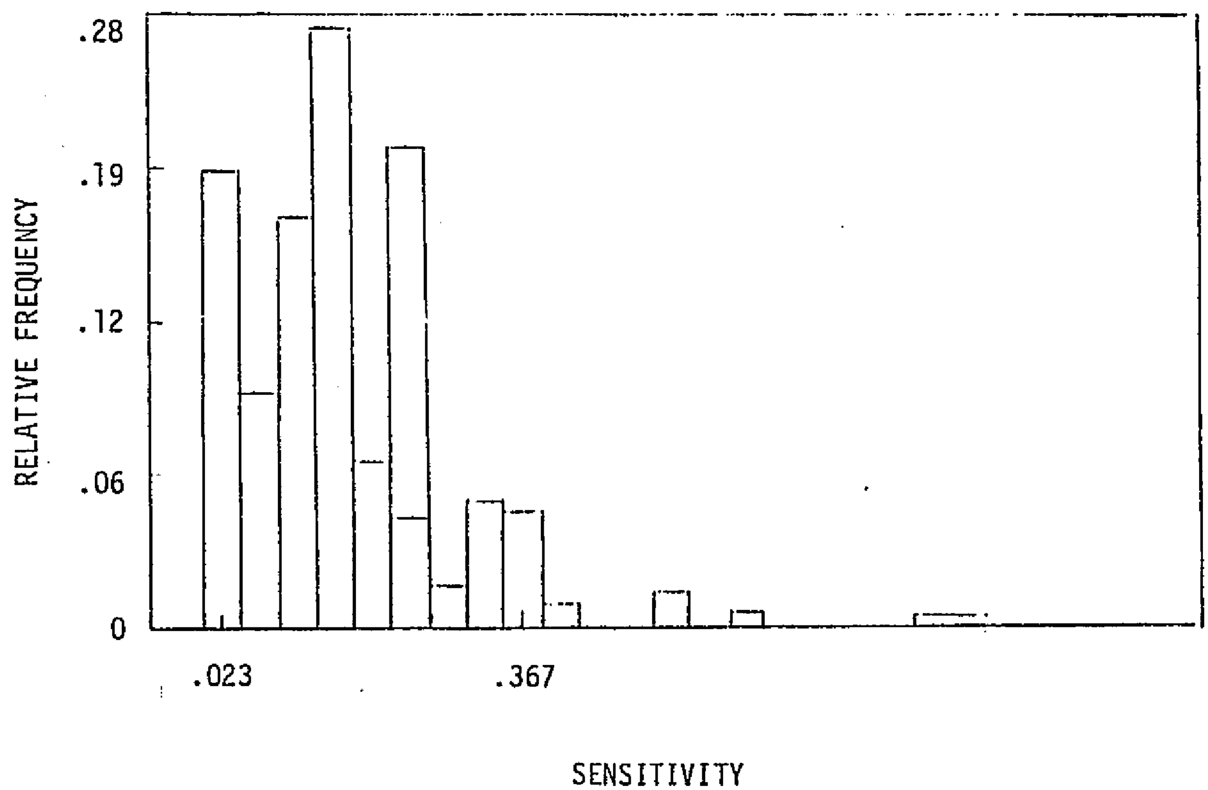


Figure A-7: Histogram of peak flow sensitivity to ED for April and May

ii) Effect on Monthly Runoff

A. Summer

The effect during this season is very minor. This is to be expected because of the small rain activity and also because only that fraction of rain that falls on the permanently impervious portion of the basin contiguous with stream channels appears as runoff, or

$$\text{runoff} = \text{PCPT} \times \text{PCTIM} + \text{baseflow comp}$$

$$\frac{\%\Delta\text{runoff}}{\%\Delta\text{PCPT}} = \frac{\text{PCTIM} \times \text{PCPT}}{\text{runoff}}$$

This is usually zero or close to it, where PCPT stands for total monthly precipitation, since PCTM = .02 and PCPT is also very small or zero.

B. Fall

At this time the rainy season begins, and the amount of PCPT is enough to fill up the UZTW storage. In this case it is difficult to justify analytically the results because of the non-linearity introduced by the filling up of the UZTW storage. Nevertheless. computer simulation yields a fairly simple relationship between runoff and sensitivity. This relationship, which is shown in Figure A-8, is valid for changes in precipitation from +40% down to -15%.

Residual effect in the Fall

This effect is also difficult to analyze because of non-linearities. The trend however is that of a constant ratio of first month's % runoff change to second month's % runoff change. As it turns out, independently of the amount of rain or % change involved, this ratio for available data is never more than .61. The only exception is the year 1966. The rain pattern for this year was such that with an increase of the input rain, the LZTW storage was forced to fill up earlier, thereby contributing an additional amount of runoff in the form of increased baseflow, making the system runoff more sensitive to rain changes. All of this discussion applies to the second month's effect.

In general, the residual effect of precipitation at the beginning of the rainy season decreases to sensitivities of less than .3 in the fourth month of the sequence. The exception to this is years for which the cumulative monthly rainfall, starting in October, does not amount to more than 12 inches by the end of December. These years will exhibit a significant peaking of the residual effect when the cumulative rainfall reaches about 12 inches. At this time, the sensitivity may be twice as large as that of the first month, when the perturbation first occurred.

C. Winter

The results for this season are somewhat unpredictable and exhibit no pattern. This is to a large extent due to the long time constant of the LZTW storage. Therefore, statistics had to be compiled for December, January, and February. The results are shown on Tables 3, 4, and 5. The residual effect on the second month is shown in Table 6.

Change	Mean Sensitivity	Standard Deviation
40	1.1	.46
-40	.86	.41
20	1.03	.44
-20	.92	.46

Table 3: Monthly runoff sensitivity to precipitation for December

Change	Mean Sensitivity	Standard Deviation
40	1.21	.35
-40	1.18	.59
20	1.12	.32
-20	1.0	.25

Table 4: Monthly runoff sensitivity to precipitation for January

Change	Mean Sensitivity	Standard Deviation
40	1.18	.59
-40	.88	.35
20	1.14	.55
-20	1.0	.25

Table 5: Monthly runoff sensitivity to precipitation for February

Month	Mean Sensitivity	Deviation
January	.39	.13
February	.76	.74
March	.48	.27

Table 6: Second month residual effect of precipitation on monthly runoff in the Winter. Month column refers to the second month.

D. Spring

Here, both UZTW and LZTW are filled to capacity. Without the non-linearity due to these two storage bins, the output of the model can be approximated by:

$$\text{runoff} \cong K \times \text{PRECIP}$$

$$S \cong 1$$

Computer runs show that this is a fair approximation, although there are some exceptions.

Residual effect in the Spring

E. Linearity of Cumulative Effect

The effect of separate changes in PCPTN is additive in a linear fashion for the spring season for monthly and peak flow. No data have been taken that verifies this, though.

For other times of the year there are no data at this time.

iii) Effect on Low Flow

This effect can take the form of a change in precipitation in the summer, or a residual effect on a change in the spring. The first effect is very small, for reasons outlined before. The second effect leads to sensitivities which are generally less than .6.

iv) Effect on Peak Flow

A. Summer

For any given day in the summer, the runoff is given by:

$$\text{runoff} = \text{PCTIM} \times \text{PCPTN} + \text{baseflow component}$$

FROM which $$S = \frac{\text{PCTIM} \times \text{PCPTN}}{\text{runoff}}$$

where PCPTN stands for daily precipitation

B. Fall

As long as the UZTW is not full, and the available rain is not enough to fill it, the above formula holds. For any month in which the UZTW fills, only statistical infromation can be provided, due to the random nature of peak runoff. The procedure in this case has been to vary the total monthly precipitation for the month, and to compute the sensitivity of the peak flow to this change for all the years for which data are available (8). Table 7 shows the mean and standard deviation of the resulting sensitivities for the first monthly precipitation. As can be seen from the table, on the

average the sensitivity is about 2.3. As far as the residual effect of this month's change on the next month's peak flow table 8 displays the mean and standard deviations of the sensitivities. As expected, a lower sensitivity of about .9 on the average is obtained.

C. Winter

The procedure is the same as that used for the fall. The results for December, January, and February are shown in Tables 9, 10, and 11, respectively. The residual effect on the second month is displayed in Table 12, on the third month it is usually less than .3.

D. Spring

A similar approach for March, April, and may, leads to an approximately Gaussian distribution of the sensitivities as evidenced by Fig. A-10. The mean of this distribution is 1.0 and the standard deviation is .4. From this, we conclude that, in about 70% of the cases, the sensitivity will be between .6 and 1.4.

% change	mean sensitivity	standard deviation
+40	2.75	1.64
-40	1.55	.49
+20	2.89	1.88
-20	2.08	.96

Table 7: Peak flow sensitivity to precipitation for month in which UZTW fills up.

% change	mean sensitivity	standard deviation
+40	.92	.65
-40	.67	.19
20	1.13	1.08
-20	.72	.22

Table 8: Residual effect of precipitation on peak flow.

% change	mean sensitivity	standard deviation
40		
-40		
20	1.55	1.26
-20	1.24	.67

Table 9: Peak flow sensitivity to precipitation for December.

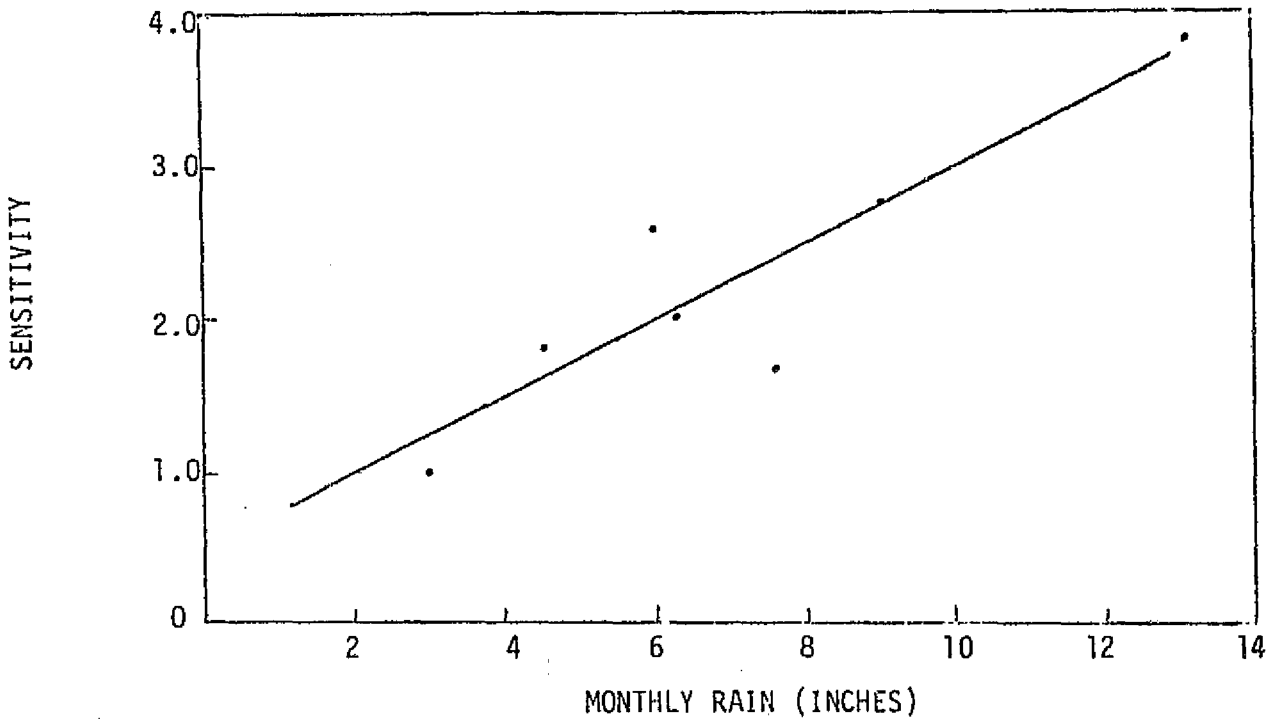


Figure A-8: Sensitivity to precipitation during first month of rainy season.

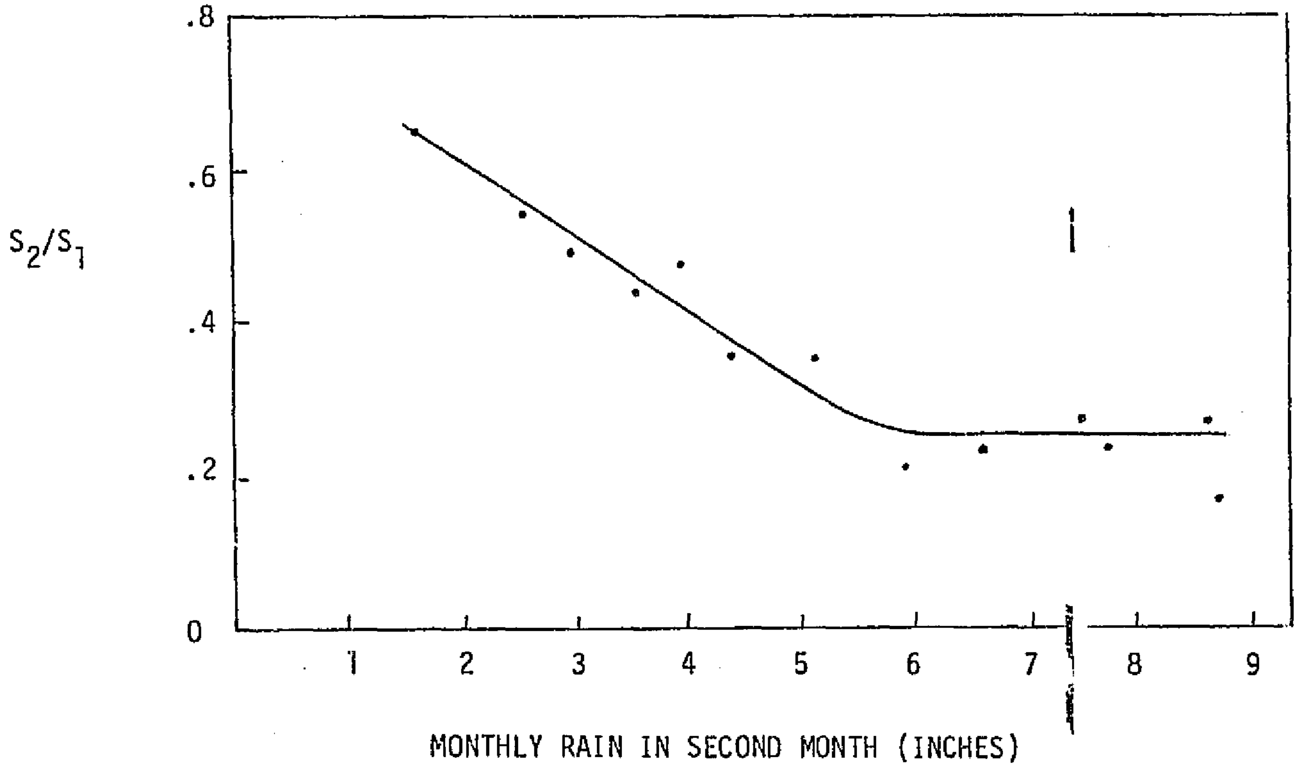


Figure A-9: Residual effect of precipitation on second month run off in the spring.

% change	mean % sensitivity	standard deviation
40	1.77	1.03
-40	1.23	.21
20	1.53	.85
-20	1.32	.48

Table 10: Peak flow sensitivity to precipitation for January.

% change	mean sensitivity	standard deviation
40	1.53	.93
-40	.90	.44
20	1.65	1.18
-20	.91	.5

Table 11: Peak flow sensitivity to precipitation for February.

Month	mean sensitivity	standard deviation
January	.33	.19
February	.95	1.09
March	.21	.21

Table 12: Second month residual effect of precipitation on peak flow in the Winter. Month column refers to the second month.

v) Storm Runoff

No data as yet.

VI. UPPER ZONE TENSION WATER CAPACITY (UZTWM)

i) Physical Basis

There is a soil moisture storage in the permeable portion of the basin. It represents the volume of precipitation which would be required under dry conditions to meet all interception requirements and to provide sufficient moisture to the upper soil mantle so that percolation to deeper zones and sometimes horizontal drainage could begin. The water in this storage is closely bound to soil particles, and is used to feed, in part, the evapotranspiration process.

The storage must be completely filled before any moisture becomes available to enter other storages.

The value of UZTWM is determined by hydrograph analysis.

ii) Effect on Runoff

This model parameter is related to the physical configuration of the basin and, therefore, is not subject to monthly variations.

In order to study the sensitivity to this parameter, it was charged by $\pm 40\%$ at the beginning of the rainy season, without changing it back for the remainder of year. Changes in runoff were examined for the first and following months. No changes at any other time were made, because the contents of the UZTW affects the behavior of the model through the ratio of UZTWC to UZTWM so that if the UZTW storage is full, this ratio always equals 1, independently of the size of UZTW storage.

Again, it is difficult to predict analytically the results of sensitivity to UZTWM, because there are two modes of behavior around the transition from partially filled to completely full UZTWM, as the percolation mechanism begins to play a role in the latter case.

Computer runs show that there is good correlation between sensitivity and the amount of runoff for the month.

The effect of a change in November can persist up through March when it can still have a sensitivity of about 1. This is most noticeable for years in which the amount of runoff is very low for that month, and for which the rain pattern is such that LZTW does not fill up until around that month.

The role of LZTW in this case is to make an additional amount of water available (in the case of a decrease in UZTW) to LZFSW and LZFPW, thereby affecting the baseflow through those two parameters. Usually high values of sensitivity to UZTWM are explained this way.

Because of a lack of data the development of a functional relationship for this parameter is not possible at this time.

Note also that no other values of in UZTWM outside of $\pm 40\%$ have been tried.

iii) Effect on Peak Flow and Storm Runoff

No data.

VII. LOWER ZONE TENSION WATER CAPACITY (LZTWM)

i) Physical Basis

This represents that volume of water held by the lower zone soil after wetting and drainage, and is generally available for evapotranspiration.

This is a very difficult parameter to determine because it is never quite completely empty, giving usually wrong estimates.

The approach to the study of the sensitivity of the model to the parameter LZTWM is the same as for VZTWM.

The results of changing this model parameter however are a little difficult to predict. This is so because the results do not immediately follow the change, but can be delayed a number of months depending on the rain pattern for the year in question. We have typically that the effects of a change in LZTW begin to show up when LZTW reaches new capacity level which is very much a function of the rain pattern.

Again because of lack of sufficient data, no functional relationship has been determined.

ii) Effect on low flow

Less than .8 in general, but can go as high as 2.0.

iii) Effect on peak flow and storm runoff

Not done yet.

VIII. IMPERVIOUS AREA (PCTIM)

i) Physical Basis

This represents the permanently impervious fraction of the basin contiguous with stream channels. This fraction of the basin then always gives runoff whenever there is any rain. For this particular basin, this fraction is .02. It is estimated by hydrograph analysis.

ii) Effect on Monthly Runoff

Methodology used to study this parameter is same as for UZTW and LZTWM. This parameter determines to a great extent the amount of surface runoff. Consequently it's effect will be most strongly felt during the time of the year when surface runoff is at its highest value in relation to baseflow and interflow. This typically happens at the beginning of the rainy season when baseflow is at its lowest, and most of the rainfall is used to meet tension water requirements.

In general, monthly flow is approximately given by

$$\text{runoff} = \text{PCPT} \times \text{PCTIM} + D(C-\text{PCTIM})$$

where D stands for any other flow components, "PCPT" is total rain for the month, and

$$C = 1-\text{ADIMP}$$

this formula should work fairly well on daily basis also

The sensitivity S is then given by

$$S = \frac{(\text{PCPT}-D)\text{PCTIM}}{\text{runoff}}$$

$$\text{ADIMP} = .03$$

since PCTIM = .02, D is approximately equal to runoff.

This formula is good to within ±15% for a change in the parameter PCTIM of ±40%.

IX. AREA OF STREAMS, LAKES, AND RIPARIAN VEGETATION (SARVA)

This parameter determines the amount of water that is evaporated from that fraction of the basin covered by lakes, streams and so on. Therefore, its effect is highest when ED is high and runoff is small. This will of course happen in the summer.

In general

$$D.R.O._i = E_i - SARVA \times EVAPT_i$$

where $D.R.O._i$ is daily runoff, and E is runoff due to all components

$$\text{month R.O.} \cong \sum D.R.O._i = \sum E_i - SARVA \sum EVAPT_i$$

$$S = \frac{-SARVA \sum EVAPT_i}{\text{runoff}}$$

the formula is accurate to within 20% for % change in parameter of ±40%.

This formula can also be used on daily basis. Good also for any time of the year.

Reference

1. Burnash, R.J.C., Ferral, R.L., and McGuire, R.A., "A Generalized Streamflow Simulation System - Conceptual Modeling for Digital Computers".

Report of the Joint Federal-State River Forecast Center, Sacramento, March '73.

CHAPTER 2b

REMOTE SENSING-AIDED PROCEDURES FOR WATER YIELD ESTIMATION

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CHAPTER 2(b)

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2b.1.0 INTRODUCTION

The central objectives of water supply studies being conducted by personnel of the Remote Sensing Research Program (RSRP) under the NASA grant remain 1) the development of remote sensing-aided techniques for estimating parameter inputs to water supply forecasting models and 2) participation in the analysis of the accuracy/cost impact of remote sensing data on water runoff estimation. The general importance of accuracy/cost improvements in water supply forecasting to both the forecasting agencies and water users has been outlined in previous reports.

Our current focus is on developing remote sensing-aided data acquisition techniques that could be used by representative water runoff estimation organizations in the state of California, namely the California Cooperative Snow Surveys (CCSS) program and the program of the Federal State River Forecast Center (RFC) both related organizationally at the state level to the California Department of Water Resources (DWR) In this regard, specific remote sensing-aided techniques are presently being developed for quantification of snow, evapotranspiration, and water impervious surface area.

This RSRP effort is being conducted in coodination with our NASA Grant participants within both the U.C. Davis (Algazi) group and the Social Sciences (Hoos) group on the Berkeley campus. Past coordination with the former group has lead to

1) an analysis of procedures and systems currently used for predicting/simulating runoff,
2) an identification of parameters important in runoff forecasting,
3) an analysis defining which of those parameters could potentially be more efficiently quantified by remote sensing,
4) an on-going analysis designed to show the accuracy sensitivity of runoff forecasting models to value changes of input parameters (see report by Algazi in chapter 2a).

The sensitivity analysis gives an early quantitative measure of the improvement in accuracy performance that can be expected if remotely sensed data can give a more precise, accurate, and current estimate of certain input parameters. Current cooperative efforts with the Algazi group involve input of remote sensing-aided evapotranspiration estimates and possibly "snow water content" estimates resulting from RSRP's contribution to DWR runoff forecasting models that are being analyzed by Algazi.

A continued analysis of the cost/accuracy efficiencies to be gained with remote sensing data in water supply estimation is being

coordinated with the U.C. Berkeley Social Sciences (Hoos) group. Specifically this effort involves continued analysis of remote sensing-aided snow water content estimation reported earlier (see Chapter 6 of our May 1975 Grant report). Possible extensions of these studies to evapotranspiration and to more complex questions of general society costs and benefits resulting from introduction of remote sensing data in runoff forecasting procedures are being considered as well.

2b.1.1 GENERAL APPROACH

The general approach being used to develop techniques for remote sensing-aided estimation of water runoff prediction parameters involves a stepwise sequence of information-need definition, sample design, measurement, estimation, and evaluation. Each of these steps is discussed briefly below.

2b.1.1.1 Definition of Information Types to be Measured and to be Estimated

This basic first step in any inventory procedure consists firstly of a definition of the general information needs/and specific parameter set to be estimated along with any assumptions and/or restrictions to be placed on the method of data acquisition, processing, or use. In the case of runoff forecasting, the general information needs, parameter set, and assumption list were given and discussed in earlier reports (our May 1974 and 1975 Grant Reports). Currently, work is proceeding at RSRP to develop remote sensing-aided procedures for snow, evapotranspiration, and impervious surface water forecasting input parameters. The snow technique has application in both the CCSS and RFC models while evapotranspiration and water impervious surface area results can be used at present most directly in the RFC model.

The next step is to define a population of data on which to develop, test, and evaluate the remote sensing-aided procedures. As indicated in the May 1974 Grant report, the Feather River Watershed (7800 km^2) has been selected as this test site. The selection was based on the adequacy of the data base available for that region as compiled at U.C. Berkeley and on the fact that the Feather River region above the Oroville reservoir represents the source watershed for the California Water Project.

Population subdivision of interest are also identified in this phase. Given the desirability of a high ratio between knowledge gained and effort expended in this study, the Spanish Creek Watershed was chosen as such a subdivision for initial techniques tests and evaluation. The Spanish Creek Watershed represents, approximately, the environment mix found over the entire Feather River region. Results and techniques developed from the Spanish Creek area can then be expanded or applied over the entire region with a minimum of technical difficulties.

Other subdivisions, or strata, important in the actual estimation process must also be defined at this time. These strata include specific snow evolution environments (a function of topographic position, vegetation, etc.) important in snow areal extent or snow water content estimation. In the case of evapotranspiration estimation, general vegetation classes would represent strata, while general geologic/additional strata for water impervious surface area estimation.

Finally all relevant and available information types that are needed in the estimation process must be identified. These include topographic data, aerial and satellite imagery/digital data, ground data, and geologic data.

2b.1.1.2 Sample Design

In order to cost-effectively tie data from many sources together to provide accurate and timely water runoff parameter estimates, a multistage sampling approach is being employed in this water supply study. With this approach to data acquisition and estimation, a smaller and smaller sample is taken from successively more resolved and more costly data planes.

Evapotranspiration estimation may be used as an example. In this case the watershed of interest is divided into a continuous matrix of rectangular sample units. Measurements are performed within each (or within a sample) of these primary sample units (PSU's) and an estimate of evapotranspiration is then derived for each PSU by application of a mathematical model. A small sample of those PSU's is selected for further subsampling. A series of large scale photo plots is then obtained along the long axis of the selected PSU's. Detailed vegetative canopy measurements are made at each of these secondary sample units (SSU's i.e. photo plots). A more refined, but more costly estimate (or a unit area basis) of evapotranspiration is again obtained through combination of vegetative and meteorological data, specific to each SSU. Finally, a very small sample of SSU's are visited on the ground. Detailed vegetative canopy and soil characteristics are measured and the most refined and costly estimate of evapotranspiration is gained.

The snow quantification (areal extent and snow water content) and "water-impervious surface area" estimation procedures also employ multistage sampling approaches. These may involve two stage samples, including either (1) satellite information at the first stage and large/medium scale information at the second (e.g. snow areal extent and one form of impervious surface area estimation), or (2) a sample of satellite data and a subsample of ground data (e.g. snow water content estimation; or (3) combinations of the above.

2b.1.1.3 Measurement

Once the sampling design has been formulated, detailed measurement procedures at each stage must be specified. Of course, the factors to be measured will depend upon the water runoff forecasting input parameter to be estimated. In the case of snow water content estimation, measurement procedures are specified for the determination of snow areal extent on sequential LANDSAT data and for the use of a snow tube for ground-based determination of snow water content. Measurement procedures for evapotranspiration are more lengthy. For example, topographic data, LANDSAT digital data, and meteorological satellite data must be measured/transformed (includes computer-mediated data classification) and combined through mathematical models to give a "measurement" of evapotranspiration (or of an evapotranspiration-correlated parameter) at the first stage of the sample design. Similar multivariate measurement and data combination procedures must be specified for data types at the second and third stages.

2b.1.1.4 Estimation

After the measurement procedure has been completed for each stage of a given sample design, the water runoff correlated parameters generated from each sample stage must be combined by a statistical formula to produce a watershed-wide estimate of that parameter. This estimate (e.g. snow water content) will be calibrated to the accuracy of the most data-resolved stage (e.g. ground level) of that particular sample design.

A measure of this estimate's standard error (level of precision) is also generated from the multistage sample. Confidence intervals around the parameter estimate, in which the actual watershed-wide (or subbasin) value of that parameter is expected to fall with given probability, may then be determined from the standard error.

2b.1.1.5 Evaluation

The estimates of runoff forecast input parameters (e.g. snow water content, evapotranspiration, water impervious surface area) may be evaluated according to a set of performance criteria. These criteria include precision improvement, accuracy improvement, cost reduction, and timeliness improvement (reduction in time to generate forecast). Each of these improvements is generally quantified in schedule form for fixed levels of one or more of the other three performance criteria.

The performance evaluation criteria are applied to the remote sensing-aided estimates of input parameters that are used in making runoff forecasts. The criteria are applied in two ways: (1) in evaluating the improvement of the input parameter (e.g. evapotranspiration) estimate relative to

conventional procedures for estimating the given input parameter and (2) evaluating the improvement of runoff forecasts resulting from use of the remote sensing-aided estimates of a given runoff forecast input parameter. Analysis with respect to the first type of evaluation was documented for snow water content estimation in the May 1975 Grant report. That study, further reported on in section 2b.2.3 of this report outlines in a precision versus cost improvement schedule the precision and cost advantages to be gained through the use of remote sensing-aided estimates of snow water content. This first type of analysis may be termed evaluation of an intermediate output in a runoff forecasting system.

The second type of evaluation, that of the ultimate output, (consisting of the runoff forecast), involves the application of the estimated input parameters (intermediate outputs) to runoff forecasting models/procedures. Improvements in runoff forecasting with respcct to precision, etc. are noted when remote sensing-aided instead of conventional estimates of input parameters are used for the forecasts.

Examples of this second form of analysis are currently being initiated in at least two areas. The first is that evapotranspiration outputs from the RSRP procedures will be input to RFC model/procedures as currently implemented by the Algazi group. Forecast accuracy improvements are to be noted. The second example involves the application of snow areal extent and snow water content estimates to simple and more complex runoff models for accuracy of precision/cost improvement evaluation.

2b.2 SNOW QUANTIFICATION TECHNIQUE DEVELOPMENT

2b.2.0 INTRODUCTION

Many investigators have used aerial photography and satellite imagery for measuring snowpack parameters. The research reported on in this section illustrates the use of two key parameters: snow areal extent and snow water content. These are gathered from analyses of LANDSAT imagery, supporting areal photography, and existing ground data. A rationale in the form of a cost-effectiveness analysis is introduced suggesting the economic viability of remote sensing-aided snowpack measurements.

The first parameter, areal extent of snow, is one that many investigators have examined. Some of the many investigators who are attempting to quantify and use areal extent of snow are listed in Table 2b.1. Several methods have been used to quantify this parameter from satellite imagery which differ greatly in approach and most likely in results. Rango and Foster (1975) have proposed a method similar to one which has long been used by investigators such as Baraes and Bowley (1967).

Their method is essentially one of planimetering the apparent snowline as seen on LANDSAT imagery to arrive at an areal extent of snow estimate. Rango, Salomonson, and Foster (1975) used this estimating procedure as an input into a water runoff prediction model in which areal extent of snow was regresssed against actual water runoff volume.

Our Remote Sensing Research Program, University of California at Berkeley has developed another way to calculate and use the areal extent of snow parameter. Areal extent of snow is measured using a two stage statistical estimation procedure that allows the final estimate to be interpreted for its accuracy. Such parameters as vegetation type, elevation, and aspect, all of which affect the appearance of snow cover on remote sensing imagery, are accounted for in this estimation procedure to give the corrected estimate of the areal extent of snow. The results of the areal extent of snow estimation procedure are then used, in part, to generate the second key parameter, snow water content.

The snow water content estimate is based upon the apparent rate of depletion of the snow as determined by the method described above combined with ground measurements collected on several snowcourses administered by the California Department of Water Resources. The final snow water content estimate is based on the statistically-derived correlation between the areal extent of snow information and the ground data. Snow water content so derived is then available for use in future remote sensing-aided water runoff models that may use other key parameters such as watershed evapotranspiration and surface and subsurface flow.

The snow water content value not only provides a more meaningful parameter than the areal extent of snow subparameter but also permits a

performance comparison with existing data on a comparison relative accuracy and cost savings basis. Initial results from this comparison have been very favorable as shown below in Section 2b.2.3.

The work reported to date reflects the partial completion of the ongoing investigation into manually-implemented techniques for snow pack quantification. Current work is directed toward refining this manual approach to better fit operational applications. Since eventual applications are likely to include computer-aided snow water content estimation, the manual interpretation approach has been designed to facilitate integration with computer-aided analysis of the snowpack parameters. The inherent limitations of human analysts in analyzing large volumes of related but deverse data make this a logical direction of research. Once computer-aided estimation systems have been developed, the digital nature of LANDSAT data can be used to full advantage toward the ultimate goal of providing accurate and timely snowpack parameter estimates for inclusion in water runoff prediction equation.

2b.2.1 AREAL EXTENT OF SNOW ESTIMATION

2b.2.1.1 Objectives

Because areal extent of snow is an accepted parameter in many snowpack measurements, methods are needed which will estimate the parameter quickly, accurately, and consistently. The objective of this study is to provide such a method along with the appropriate sampling design so that stated accuracy figures can be verified and analyzed in their proper perspectives.

2b.2.1.2 MATERIALS AND METHODS

The method used to estimate areal extent of snow at the Remote Sensing Research Program is based upon the analysis of LANDSAT color composite imagery (Appendix I) divided into equal image sample units (ISU's). Two dates of LANDSAT color composite imagery are used for analyzing each snowpack date. For instance, if the areal extent of snow is to be calculated for the April 4, 1973 LANDSAT overpass of the Feather River Watershed, a LANDSAT color composite of April 4, 1973 and a LANDSAT color composite on a cloud-free summer date such as August 13, 1972, would be used. The LANDSAT winter date, April 4, is gridded with image sample units (each equaling 400 square hectares in the prime preliminary analysis) while the other date is not. The two dates are superimposed using either a stereoscope or a zoom transfer scope. The cloud-free summer date provides the interpreter with information primarily on the various vegetation/terrain communitee (which impacts the way in which snow appears from the air), and also on aspect and elevation, both of which are very important in the manner in which snow appears. By combining these two images optically the interpreter can better estimate why the snowpack appears as it does on the LANDSAT imagery. The result is that accurate and consistent snow areal extent estimates specific to

*The work reported on in this section is considered to be complementary to, and not duplicative of, work currently being performed by NASA/Goddard personnel under the title "GSFC Snow Mapping ASVT".

given sample units are possible.

At the time of a LANDSAT overpass low altitude aerial photography is flown over randomly selected transects in the appropriate watershed. The image sample units as they appear on the LANDSAT imagery are transferred to the aerial photography.

Estimates are then made of the percent of snow on the ground as it appears on the aerial photography in each ISU. These estimates are placed into the five snow cover condition class categories used for the preliminary part of this study. Approximately one-half of the image sample units as they appear on the aerial photography are used in the training of the interpreter, the other one-half to be used for the testing of the interpretation.

The interpreter, thus armed, views the training image sample units on the two dates of LANDSAT imagery. He uses the snow cover condition class estimates on the training ISU's found on the aerial photography to guide the training. Once trained, the interpreter then interprets the guidded LANDSAT winter data (with the summer date superimposed) image sample unit-by-image sample unit except for the training ISU's. Some of the image sample units he interprets are those found on the supporting aerial photography for testing. The interpreter's classification of these "testing" ISU's on the LANDSAT imagery is then statistically related to the snow cover condition class estimate on the "testing" ISU's found on the aerial photography by a ratio estimator statistic. This statistic is then used to correct the interpreter's estimate of the areal extent of snow from LANDSAT data.

The test area used for the areal extent of snow analysis was the Feather River Watershed in the Northern Sierra Nevada, California. Three dates in the spring of 1973 were analyzed: April 4, May 10, and May 18. The areal extent of snow results along with accompanying confidence intervals are seen below in table 2b. For a more complete treatment of this technique and the results see the May 1975 section of this NASA Grant report.

Current research activities involve the refinement and expansion of this areal extent of snow estimation technique. Since the preliminary investigation provided variances of the estimate, such factors as sampling rate (of low altitude aerial photography) and optimal grid (or ISU) size can be calculated by testing this procedure over more dates and more areas. Further studies comparing the other various methods of areal extent of snow estimates can be compared to allow potential uses to choose the method which best suits their cost and accuracy needs.

2b.2.1.3 CONCLUSIONS

Much of the U.C. Berkeley research already completed in areal extent of snow estimation may be considered operational depending on the actual needs of the particular user. However, in many cases not even the user

knows what accuracy or cost requirements are applicable for this parameter. Further investigation in both the manual and computer-aided analysis of areal extent of snow is needed to be able to present the user a choice in the level of sophistication he needs or can afford.

Several facts seem evident from the research completed to date. The double sampling method which in effect "calibrates" the LANDSAT imagery provides an extremely good way of analyzing the data. The general approach multistage sampling, has been used successfully in several other remote sensing research experiments involving manual and computer-aided analysis. Therefore, it seems likely that this or a similar sampling system will be used for the remainder of the areal extent of snow research.

The design of this project facilitates the performance of valid statistical analysis. This is extremely important so that future results from different approaches can be analyzed with respect to prior research. Confidence intervals were applied to all areal extent of snow estimates thus providing accuracy of results figures.

Probably the greatest advantage of this approach is that it not only corrects the interpreter's snow areal extent classification, to plot/ground values based on testing results, but it also minimizes variation in final classification results between interpreters. Thus, a consistent result can be expected even though areal extent of snow estimation is performed on different areas by different interpreters.

Ultimately, it is the user's data requirements that determine the weight assigned to the snow areal extent and snow water content parameters. The image sample unit grid system, however, provides a flexible and convenient base on which to build a whole variety of snow and non-snow parameters. The following section deals with snow water content estimation, and how areal extent of snow estimation is used for that purpose.

2b.2.1.4 FUTURE RESEARCH

Up to this date reserach into areal extent of snow estimation has been conducted almost exclusively in the manual phase. As more parameters (such as vegetation/terrain classification, elevation, aspect, precipitation, soil type, and image digital reflectance values, etc.) which impact snow cover are used in the estimation procedure it becomes necessary to use analysis systems which can handle all of the data conveniently. In this regard, the digital nature of the LANDSAT date along with the large amount of parameters potentially useful for classification dictate a computer-aided approach to analysis.

The actual extent to which computer-aided analysis will be used can only be determined by research. The possibility exists for manual/automatic analysis where the interpreter may analyze a computer generated enhancement thus making optimal use of human and computer abilities. By design, the

automatic computer-aided approach will follow the same approach as employed in the manual method. In the manual interpretation, image sample units of approximately 400 hectares each were analysed for snowpack based on LANDSAT reflectance values, underlying vegetation/terrain feature, elevation, and aspect. The computer-aided analyses will look at small blocks of pixels and analyse each based on the above parameters and possibly others. This design allows accurate comparison to be made of the various systems useful in estimating areal extent of snow.

The tentative outline for the completion of current and future research in areal extent of snow estimation can be found in table 2b.2.

TABLE 2b.1

A Partial List of Investigators* Using or Performing Research on Areal Extent of Snow

School of Renewable Natural Resources, University of Arizona, Arizona

Water Resources Research Institute, University of Wyoming, Laramie, Wyoming

Institute of Water Resources, University of Alaska, Fairbanks, Alaska

Remote Sensing Research Program, University of California, Berkeley, California

Geology Department, University of Maryland, College Park, Maryland

Department of Geography, University of Zurich, Zurich, Switzerland

NASA/Goddard Space Flight Center, Greenbelt, Maryland

United States Geological Survey

M.W. Bittinger and Associates, Inc., Fort Collins, Colorado

Snow Surveys Branch, California Department of Water Resources, Sacramento, California

Snow Survey Unit, Soil Conservation Service, U.S. Department of Agriculture, Denver, Colorado

Bonneville Power Administration, Portland, Oregon

National Weather Service

Corps of Engineers, North Pacific Division

National Oceanic and Atmospheric Administration, National Environmental Satellite Service

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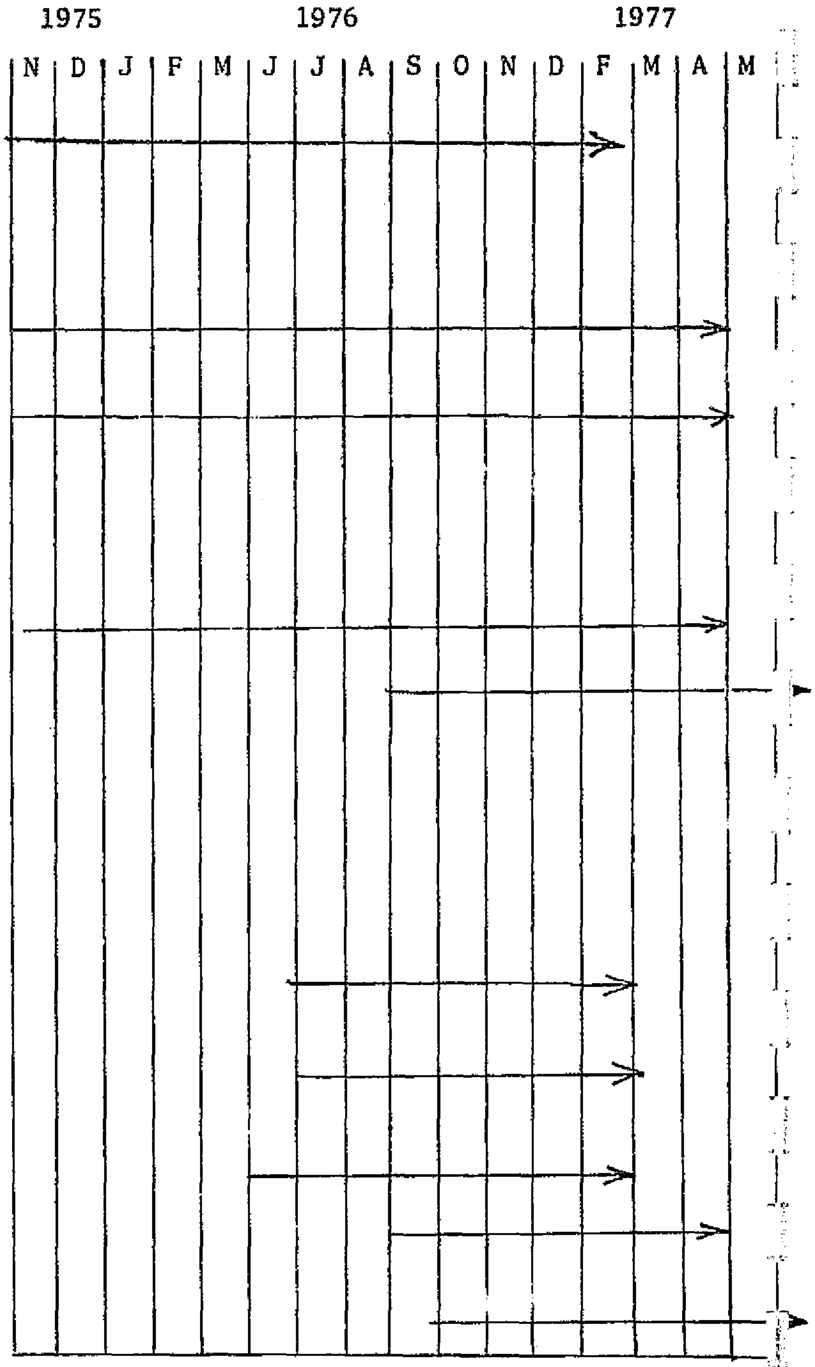
*Participants in the "Workshop on Operational Application of Satellite Snowcover Observations", August 18-20, 1975 at the Waystation, South Lake Tahoe, California. NASA/Goddard Space Flight Center in cooperation with General University Extension, University of Nevada, Reno.

TABLE 2b.2

Snow Quantification Snow Areal Extent



I. Manual Analysis

A. Refine and
Optimal Grid Size, Sampling Rate, Stratification, Snow Cover Class Size, Procedure Efficiencies

B. Demonstration of Techniques over more years are more dates

C. Determination of Impact on Water Yield Forecasting Error

1. Regression Equations
2. Interfacing with more complex models

D. Update Cost Analysis

E. Technology Transfer

1. California Cooperative Snow Survey

2. Others

II. Automatic Analysis

A. Multidate Discriminant Analysis

B. Data Bank Snow Quantity Determination

C. Sampling

D. Impact on Water Yield Estimation

F. Technology Transfer

2b.2.2 SNOW WATER CONTENT ESTIMATION

2b.2.2.1 Objectives and Justification

The immediate objective of the U.C. Berkeley Snow Water content research is to determine if LANDSAT data and a small calibrating sample of snow course measurement data can be readily integrated into operational snow quantity estimation schemes. The goal of this integration would be to provide less costly, more accurate, and potentially more frequent estimates of watershed snow water content than available through current forecasting procedures. The second objective of this study is to determine if this remote sensing-aided snow quantification approach will yield more accurate, less costly, and more timely (i.e. quicker) estimates of water runoff.

The basic analysis framework, first data set results, and discussion for the immediate snow water content objective were given in Chapter 6 of the May 1975 Annual Progress Report for this NASA grant. Results reported there indicated substantial improvements in snow water content estimate and/or cost reductions could be obtained with LANDSAT data used as a supplement to current ground snow course measurement procedures.

As noted in the May report, such improvements could provide substantial additional forecast information to water forecasting agencies. This situation is especially true in the Sierra hydrologic system, where snow melt provides a majority of the runoff. Adequate snow water content information is therefore especially important in water supply forecasting models for such environments. Currently the California Cooperative Snow Surveys (CCSS), a state agency involved in water supply forecasting, is cooperating in this research. It is anticipated that the resulting procedures/results will also be tested with the Federal-State River Forecasting Center's (RFC) water yield model via a coordinated effort with the U.C. Davis Algazi group.

Beneficiaries of this information would also include users of snow melt runoff water, viz: farmers, ranchers, industrial plants, and homeowners. Improved knowledge regarding the future availability of water for these groups would statistically tend to reduce momentary losses incurred by their assumptions that either more or less water would be available when in fact the actual situation turned out to be otherwise.

This report will concisely review the on-going and projected research effort as in remote sensing-aided snow water content estimation technique development. Interfaces with other investigators, user organizations, and general runoff prediction will also be discussed.

2b.2.2.2 General Approach

The approach to remote sensing-aided snow water content estimation under development and evaluation in this study may be summarized as follows:

The estimate may then be related by regression equations directly to basin water yield for a given period. Or the estimate may be used as another predictor variable in current snow survey or river forecast organization runoff prediction equations.

Performance (Estimate Adequacy) Criteria

Performance criteria for this snow water content estimation procedure consist of an estimate precision versus budget schedule and a timeliness factor. The greater the precision for a given budget and the more quickly the estimate is available, then by definition the greater the performance or capability of the system. Performance will also be judged by the improvement in precision and reduction in possible bias with which water yield is estimated.

2b.2.2.3 MATERIALS AND METHODS

As already discussed, the LANDSAT-aided snow water content estimation system used in this study is known as a stratified double sample. Its objective is to combine snow water content information for the whole watershed, as obtained inexpensively from LANDSAT data, with that gained from a much smaller and more expensive sample of ground-based measurements at snow courses. Image sample unit costs and accuracies are derived from concurrent RSRP work in the Spanish Creek Watershed, a sub-basin within the Feather River Basin.

The stratified double sampling plan is described mathematically by Thomas and Sharp (1975). The manual method can be summarized in eight steps described below. An automated method under consideration involving replacing the first three steps with digital analysis of LANDSAT data and/or using of a computer data bank approach for determining snow water content on a sample unit basis, (see sections).

Step 1: Create LANDSAT color composites with appropriate image sample unit (ISU) grid over watershed(s) of interest. Black-and-white LANDSAT transparencies are obtained and transformed into a simulated infrared color composite (from Katibah, 1973). In the color-combining process, an ISU grid is randomly placed over each image so as to cover the watershed of interest. ISU's in this study represented areas of about 400 hectares (980 acres). The Feather River Watershed covers approximately 780,000 hectares.

Step 2: Estimate snow areal extent by LANDSAT ISU for previous year(s) or current season snow build-up dates. Each ISU is interpreted manually as to its average snow areal extent cover class according to a snow environment-specific technique developed by Draeger and Lauer (1973) and extended by Katibah (1975).

Sample Design and Measurement

A stratified double sample procedure is used to develop a basin-wide estimate of snow water content. Under this approach, snow water content information for the whole watershed, as obtained inexpensively on a sample unit basis from LANDSAT data is combined with that gained from a much smaller and more expensive sample of ground-based measurements at snow courses (see Figure 1). The result will be a basin-wide estimate of snow water content based on LANDSAT data calibrated by regression on snow course data. Since much of the watershed snow water content variation is accounted for by information gained at the first or LANDSAT sample stage, overall estimate of basin snow water content is possible at significantly more precise levels than available for the same cost from conventional snow course data alone.

The sequential sampling/measurement process proceeds by first locating a sample grid over the watershed. Snow areal extent estimates are quickly made for each sample unit by manual and/or automatic techniques for the previous snowpack build-up dates and then for the specific forecast dates. These snow areal extent data are then combined by a linear (and/or more complex realistic) model to generate a snow water content correlated index parameter specific to the forecast date for each sample unit. All watershed sample units are then sorted into classes (or strata) according to the relative size of their calculated snow water content index.

Specification of the desired basin-wide snow water content estimate precision and level of confidence, together with a determination of the available budget allows a calculation of the necessary ground subsample size. Ground snow water content measurements are then allocated to LANDSAT-based snow water content-index strata according to weighted random stratified sampling procedures.

Regression relationships are developed between the LANDSAT snow water content index data and the ground snow water content measurements. These equations are then used to correct all LANDSAT data to ground values of snow water content. The ground corrected values of LANDSAT-based snow water content information in each stratum or class are added to give a total basin-wide estimate of snow water content together with an associated precision statement.

Outputs and Their Applications

The proposed LANDSAT-aided snow water content estimation system is designed to generate an estimate of total watershed snow water content and an associated statement of precision for a given forecast period.

Step 3: Estimate snow areal extent by ISU for LANDSAT snow season forecasting date of interest.

Step 4: Transform snow areal extent data to snow water content data by LANDSAT ISU. Snow water content is estimated from the following first case, time specific model:

$$X_i = \sum_{j=1}^{J} (M_{ij})(G_j)\ K_i$$

where X_i = estimated snow water content index for image sample unit i, correlated to corresponding actual ground snow water content data,

M_{ij} = snow cover midclass point based on photo interpretation; expressed on a scale of 0.00 to 1.00 for image sample unit i on the jth LANDSAT snow season date,

G_j = weight assigned (0.00-1.00) to a past M_{ij} according to the date of the current estimate,

K_i = the number of times out of j that sample unit i has greater than zero percent snow cover, and

J = total number of snow season dates considered.

To insure reasonably high correlation between X_i and corresponding snow water content values, there usually should be at least three snow season dates considered ($j \geq 3$);. Normally, one or two dates of LANDSAT imagery would be required during the early snow accumulation season. Occasionally, j may be only two, such as when the first date consists of an April 1st snow water content map based on the past year's LANDSAT data . In all cases the sample unit grids on all dates must be in common register with respect to a base date grid location (see Figure 2b.1).

Step 5: Stratify ISU's into LANDSAT snow water content index classes, if not already performed. Then calculate by stratum the number of ground sample units (GSU's) or snow courses required to achieve the allowable error criteria for the basin snow water content estimate. The number of required ground samples may be determined (Thomas and Sharp, 1975) for individual strata according to the snow survey direct cost budget for the watershed of interest and according to the following stratum specific statistics: relative stratum size, LANDSAT snow water content variability, LANDSAT to ground snow water content data correlation, and LANDSAT to ground sample unit cost ratio. This study employed

six snow water content index strata, with water content index values ranging from less than 0.1 to over 8. Such stratification was used to control the coefficient of variation of the overall basin snow water content estimate.

Step 6: Allocate the CSU's calculated in Step 5 among snow water content strata with equal probability within strata in accordance with stratified random sampling requirements. The following table summarizes the number of image and ground sample units required in each of six snow water content strata, covering the Feather River Watershed, given a cost per ISU of 15¢ and a cost per GSU of $150.

LANDSAT Snow Water Content Stratum	1	2	3	4	5	6	
Snow Water Content Index Range	0.00-0.10	0.10-0.35	0.35-<1.00	1.00-<3.00	3.00-5.00	>5.00	TOTAL
No. of LANDSAT ISU's Examined in Watershed	503	614	205	393	220	283	2,218
No. of ISU's Visted on Ground	0	3	1	7	4	11	26

TABLE 2b.3

Step 7: Calculate the estimate of watershed snow water content according to a summation of strata-wide snow water content estimates generated from regression equations relating the LANDSAT snow water content index data in each stratum to the corresponding sample of ground snow water content measurements.

Step 8: Enter the basin snow water content into statistical or physical models to predict water yield. For example, the watershed LANDSAT-aided snow water content estimate could serve as a predicting variable in a regression equation developed to predict water runoff.

The test and development procedure for Step 8 is presently conceived as a two phase procedure. The first phase involves relating the predicted basin snow water content for a given forecast date directly to snow melt runoff for a selected period of time. This relationship will be formulated by a simple regression analysis. The second, more sophisticated

phase of runoff analysis, will be to employ resulting snow water content estimates in current empirical and physically realistic runoff models presently used by water yield forecasting agencies. In both cases the partial correlation between snow water content and runoff will be determined. The improvement in runoff prediction precision and reduction in forecast error and direct estimate cost by use of the remote sensing-aided estimate of snow water content will be examined in the case of water yield forecast model types presently in use.

The automated approach to snow water content estimating would involve a computerized procedure employing discriminant analysis and real-time data bank technology. It results in discriminant analysis of LANDSAT digital data together (optionally) with topographic and climatic data planes as can be combined through stochastic and/or deterministic functions to arrive at sample unit by sample unit snow water content correlated index estimates. Remaining steps in the procedure are unchanged.

The lost, and certainly very important, aspect of this research involves a dialogue and interaction with potential user agencies. As mentioned earlier, such a feedback process currently exists between U.C. Berkeley and the CCSS. The first objective of such interaction includes refinement of the snow water content technique itself so as to maximize the benefits to that user. This effort involves an examination of technique modification so as to most easily incorporate the LANDSAT-aided approach into user work procedures. The second aspect of this projected effort involves the actual transfer of this technology to users such as the CCSS Program and the RFC. Training and feedback programs with these groups will be a necessary part of such a task in order to insure a workable operational methodology.

2b.2.2.4 RESULTS

Results to date indicate a correlation coefficient of .8 - .85 between LANDSAT snow water content index data on a sample unit basis and corresponding ground snow water content measurements. Factor of two cost or precision improvements for estimation of basin-wide snow water content using LANDSAT-aided versus conventional snow course measurement systems appear possible in some circumstances.

The LANDSAT-aided system has yielded relatively precise estimates of total watershed snow water content. For the current $4,200 monthly snow survey CCSS budget value specific to the Feather River Watershed, the LANDSAT-aided approach estimated true basin snow water content to within ±3.6% ninety-five times out of a hundred (see Chapter 6 of the May 1975 Grant Annual Progress Report).

Results of snow water content estimation on more dates over more seasons are presently pending. Also pending are the LANDSAT-aided systems impact precision, cost, accuracy improvements on water yield estimation

and the impact of automatic techniques in the first three steps on snow water content estimation.

2b.2.2.5 DISCUSSION/CONCLUSIONS

The results obtained to date indicate substantial potential cost and/or precision advantage to be gained by use of convention ground measurement snow course data integrated in a double sampling framework with LANDSAT-derived information. It is expected that further improvements in watershed-wide snow water content estimate precision can be obtained by optimizing image sample unit size and utilizing more snow accumulation/melt environment-specific manual or computer data bank-mediated snow quantity decision rules.

Forthcoming results of LANDSAT-aided snow water content estimates on water yield prediction performance/capability in terms of cost, precision, and accuracy should provide further guides for optimization of the foregoing procedure. In addition, precision/cost relationships during other seasons and other years must be obtained to demonstrate the consistency of the results. Ultimately, user feedback and interaction will be instrumental in the test and evaluation procedure as well as in refining the technique for operational use.

The LANDSAT-aided snow water content estimation system under development and evaluation in this study offers several additional possibilities for future snow survey work:

One biproduct of the LANDSAT-derived image sample unit data is an in-place mapping of snow water content with respect to known melting environments and stream channels. Such time- and place-specific snow melt records could be used to aid in the selection of new snow course sites or in the placement of automatic snow sensors. Snow pack and relative stream channel position data could also be used in refined models of runoff timing.

Human and automatic analysis of daily environmental (meteorological) satellite data, when correlated with less frequent LANDSAT and ground data, offers the possibility of extremely frequent watershed snow water content updating.

Hydrologic models of the future will conceivably integrate remote-sensing and meteorological data with automatic ground-based snow sensing equipment. Real-time information eventually could be generated for entire watershed or subbasins, depending on the need to assess the impact of a major storm or a minor subdivision. The continued refinement of remote sensing-aided snow water runoff estimation procedures is likely to be a necessary input into future water resource management practices.

This study suggests that remote sensing promises great potential for aiding in the snow water content estimation process. These findings are further enhanced by the fact that snow water runoff is one of the major sources of water supply within the California Water Plan, as well as in many other parts of the world. Improved methods of identifying, monitoring, mapping, and modeling our snow water resources at this time can lead to improved methods of predicting and managing this resource in the future.

2b.2.2.6 RECOMMENDATIONS FOR FUTURE WORK

In order to demonstrate to the research and user community the feasibility, utility, and reliability of the proposed LANDSAT-aided snow water content estimation procedure the following tasks should be initiated or completed in the coming year.

1. The LANDSAT-aided snow water content estimate versus budget schedules, and LANDSAT snow water content index to ground snow water content values correlation coefficients should be determined for several different hydrologic years and dates within hydrologic years.

2. Cost, precision, and accuracy affects of the LANDSAT-aided basinwide snow water content estimate on water yield prediction in both short run and longer run forecasting time frames should be determined. Both simple regressing and more complex (CCSS, RFC) water forecast models are projected to be examined.

3. Problems associated with the incorporation of the LANDSAT-aided system in operational (user organization, e.g. CCSS or RFC) snow water content estimation and/or water yield forecasting should be identified and solutions proposed, then tested.

Of second priority in this on-going snow water content research are the following tasks:

1. Improvement of snow water content estimate precision by statistical optimization of sample unit grid size, snow water content strata thresholds, and/or specification of more environment-specific manual snow quantification decision rules.

2. Further development of automated sample unit-specific automated snow quantification procedures. This effort would parallel the computer data bank approach to snow areal extent estimates described in section where LANDSAT digital data subjected to discriminant analysis is combined through physically realistic algorithms with topographic and climatic data to produce snow quantity values. Methods similar to the

automatic analysis for remote sensing-aided evapotranspiration estimation described in section would also be used to -etermine if additional gains in precision, accuracy and reduction in costs might be gained by introducting of automatic techniques.

3. Development and evaluation of frequent watershed snow water content updating with manually or automatically analyzed environmental (meteorological) satellite data correlated to LANDSAT and ground data is a potentially important additional research task.

4. Development of microlocation-specific (in-place) snow melt runoff models using melting environment and stream channel juxtaposition sample unit data available through the LANDSAT-aided system is another area promising significant results. Use of such environmentally-specific sample unit data in further runoff calibration of current ground snow measurement sites or allocation and calibration of new "fixed" automatic sensors is another possibility.

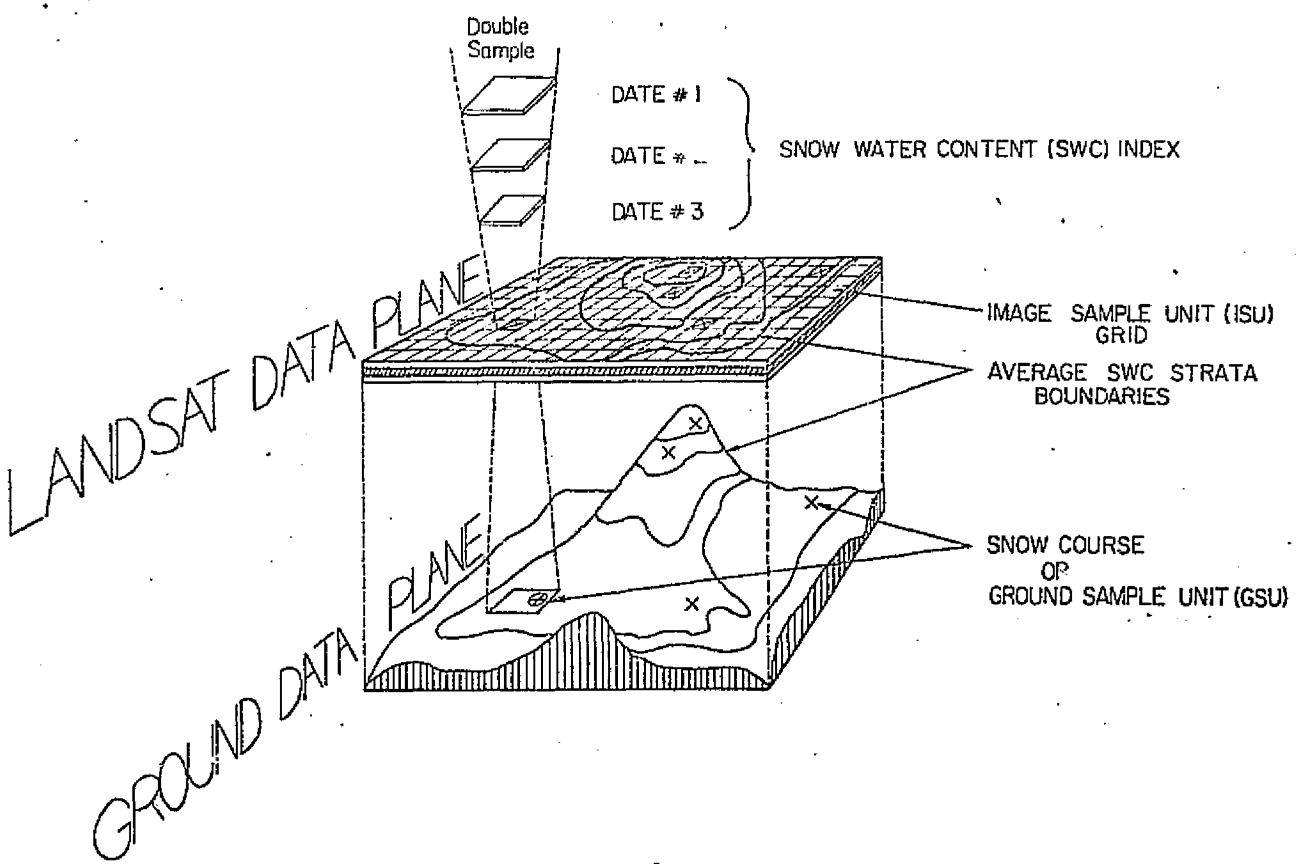


Figure 2b.1 Stratified Multidate LANDSAT data plane calibrated by snow course measurements for watershed snow water content estimation.

2b.2.3 COMPARITIVE COST-EFFECTIVE ANALYSIS

2b.2.3.1 Background

Comparative evaluation of snow water content estimation procedures is an explicit and integral part of the U.C. Berkeley snow research project. The original objective for this work, stated in the May 1974 Annual Progress Report (Thomas et al.), is "to determine if remote sensing can be cost-effectively integrated with data presently used in the California Cooperative Snow Surveys (volumetric) model to produce potentially more precise and accurate estimates of water supply" (emphasis added).

The side-by-side comparison of the operational and LANDSAT-aided snow water content estimation systems was facilitated by a blending of statistical and economic theory. Multistage sampling enables an investigator to calibrate a large number of low-cost orbital observations with a small number of ground-based observations. Optimal sample sizes were derived using a stratified double sampling scheme, as previously described.

The statistical concepts of coefficient of variation (CV) and allowable error (AE) help provide a common measure of relative performance between the competing snow water content estimation systems. Coefficient of variation describes a sample's data dispersion about its mean. Allowable error extends the CV concept by enabling a researcher to make a probabilistic statement concerning the precision of an estimated value. This is done by defining a confidence interval about the estimated mean in which the true value will fall a specified portion of the time. Cost-effectiveness analysis is a public investment appraisal technique that offers a means of evaluating relative performance in terms of both precision and cost. It helps a decision-maker answer questions about how to achieve a given set of objectives at the least cost, or conversely, how to obtain the most effectiveness from a given set of resources. Unlike benefit-cost analysis which attempts to quantify in commensurable monetary terms both the benefits and costs stemming from alternative actions, cost-effectiveness analysis allows the use of multiple, non-commensurable measures on the benefit side. Economic benefits are stated in terms of cost savings. This study employs one variant of cost-effectiveness analysis, known as a "system comparison study", to make a side-by-side comparison of operational and LANDSAT-aided snow water content estimation systems.

Figure 2b-2 illustrates a comparative cost-effectiveness framework by showing the effect of technological progress on the cost-capability "frontier" of an existing production system. The frontier F_0F_0 shows the maximum capability that can be expected from the present system at a given level of budget. A system producing on the frontier is defined as "cost-effective" because a decrease in cost is not possible without a decrease in capability. A technological advance would not beneficially alter this relationship: the cost-efficient frontier would be pushed out to some new set of points F_1F_1. A point P_0 on the old frontier F_0F_0 would not represent an inefficient pattern of production. A set of points in the shaded area of Figure 2b-2 would represent an improved return, with cost-efficient points now lying on F_1F_1 between P_1 and P_2. The effect of technological progress thus ranges between equivalent capability at a lower budget (P_1) and greater capability within the same budgetary constraints (P_2).

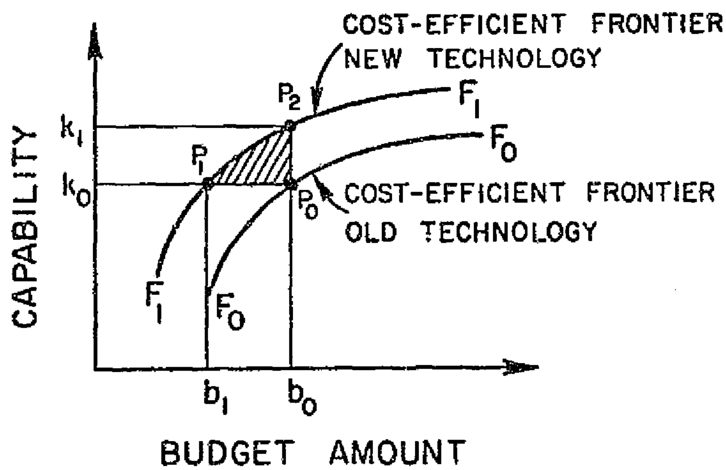


FIGURE 2b.2 EFFECT OF A TECHNOLOGICAL ADVANCE ON A COST-CAPABILITY PRODUCTION FRONTIER

2b.2.3.2 MATERIALS AND METHODS

Design and evaluation of a LANDSAT-aided approach to snow water content estimation required a thorough examination of the currently operational system. The California Cooperative Snow Survey (CCSS) program, the principal source of water supply forecasts in California, was examined both qualitatively and quantitatively.

The stated objective of the CCSS program is to "reliably predict the state's snow-melt runoff as necessary to meet the annual operating needs of California's water using agencies". Since 1929, the Department of Water Resources (DWR) has coordinated California's program of snow surveys and water supply forecasting. Around fifty cooperating agencies including the DWR participate in the program, providing services, materials, and financial support for snow survey work throughout the state. Data from snow course measurements, aerial marker surveys, and automatic sensors are combined by the DWR's Snow Surveys and Water Supply Forecasting Branch with precipitation, runoff, and water storage data. Water runoff forecasts are the major output of this process. They are provided for twenty California watersheds in which snowmelt constitutes a significant portion of annual water yield. The forecasts are published in DWR Bulletin 120 titled "Water Conditions in California" and issued five times a year. Cooperating agencies in turn apply the Bulletin 120 forecasts to their own water management programs. Within the entire CCSS program, snow water content must be viewed as an intermediate output. The snow water content index is, however, a major predictor variable and input to CCSS watershed-specific water yield prediction models. (Thomas et al., 1974). Cost or precision improvements in this variable can be expected to translate directly into improvements in water yield forecasts.

Annual costs for the entire snow survey and water supply forecasting activities of the DWR are officially budgeted at around $300,000. The DWR estimates (very roughly) that CCSS program cooperators contribute unaccounted services valued at around $200,000 a year. This implies an "unofficial" snow survey and forecasting annual budget of around $500,000. Program costs within the budget are allocated about 50:50 between survey support and forecast activities.

CCSS program budget information, although useful for examining the snow surveys production process as a whole, does not reveal much about the costs of producing intermediate outputs like snow water content measurements. Moreover, cost estimates were needed for producing these outputs in the Feather River Watershed study area, rather than for the entire state. Based on 1974 survey information and discussions with DWR personnel, it was determined that the average direct costs of the two survey types differ by about a factor of ten:

Aerial marker survey measurement visit $\approx$ \$15

Snow course survey measurement visit $\approx$ \$150

Snow aerial marker visits are relatively inexpensive because a skilled pilot can photograph many markers in a short period of time. Snow course visits, because they require detailed ground measurements, cost much more, ranging from around \$60 each for the most accessible courses to well over \$200 for remote courses accessible only by foot.

Estimates of indirect costs are much harder to derive than direct costs. The object in this study was to isolate those indirect costs associated with the production of snow course measurements. Indirect costs were distinguished in the following DWR snow survey activities: Coordination, communication, preseason setups, equipment acquisition and maintenance, training, and formal publication of measurements. It was determined that indirect costs amounted to roughly one-third of the direct costs associated with the snow survey efforts. For the Feather River Basin in 1974, with 3 aerial marker visits and 125 snow course visits, total survey costs (C_{FRB}) were estimated as follows:

$$C_{FRB} = 1.33\ (3(\$15) + 125\ (\$150))$$

$$C_{FRB} \approx \$25{,}000$$

By assuming a uniform distribution of direct and indirect costs over the snow sampling season, it is possible to estimate how much of the annual snow survey budget is consumed in a "typical" snow survey month. April and May were considered typical survey months in this study. A monthly proportionality factor was derived for April and May and applied to the basin total cost budget (Thomas and Sharp, 1975). The monthly direct costs allocated to survey work were estimated to be roughly \$4,200.

Ideally, this study would compare the existing DWR CCSS volumetric water yield model with an identical model augmented with remotely-sensed snow survey information. In reality, this study isolates those portions of the CCSS model that can be compared with LANDSAT-derived snow areal extent information developed in the University of California, Berkeley, Remote Sensing Research Program (RSRP). The analysis here thus compares the relative abilities of two systems to generate an intermediate output--basinwide snow water content. Since this output is utilized similarly in both systems to predict water runoff, a common measure of relative system performance is possible. Snow water content estimation errors in either system will affect corresponding runoff forecasts in a similar manner. Both are intended to characterize, at least in part, the snowpack variability as it relates to water content.

The methodology underlying the LANDSAT-aided snow water content estimation system was described in Section 2b.2.2. The system is designed

to generate an estimate of total watershed snow water content and an associated statement of precision, i.e., reliability. The estimate may then be related by regression equations directly to basin water yield for a given runoff period. Or the estimate may be used as another predictor variable in current snow survey runoff prediction equations. The desired result is that, after calibration by regression of LANDSAT data on snow course data, an overall estimate of basin snow water content is possible at significantly more precise levels than available for the same cost from conventional snow course data alone.

Determining costs in the LANDSAT-aided snow water content estimation system involves mixing costs developed in both the operational and LANDSAT-aided approach. Since the collection of water content samples at snow courses is an activity common to both methods, it was possible to apply the same set of costs per ground sample unit. The unit costs of typical snow course measurement visits were estimated earlier at \$150. Aerial marker measurements visits do not constitute a significant portion of the snow survey budget within the Feather River Basin.

Costs per image sample unit, applicable to only the LANDSAT-aided survey system, were developed along with the sampling methodology described previously. They are derived from actual University RSRP snow survey work using 2218 image sample units in the Feather River Watershed. The average cost for each ISU was 13.6¢, of which about 10¢ went toward interpretation and keypunching. The above sample allocation calculation instead used ISU's costing 15¢ each. Since most of the processed and unprocessed imagery is useful for later training and comparative analysis, an amortization factor was applied. It was assumed, for example, that two out of three dates of imagery developed for one location would be usable over a total of five separate occasions (Thomas and Sharp, 1975).

2b.2.3.2 RESULTS

Use of the allowable error (AE) formulation described earlier permits a direct cost-capability comparison of the two snow water content estimation systems. For the LANDSAT-based sample sizes, AE's were calculated for monthly direct cost budgets of \$1,000, \$3,000, \$4,200, \$5,000 and \$7,000 at confidence intervals ranging from 80% to 99%. For the CCSS system of snow water content estimatiom, AE's were calculated at four confidence levels on a monthly direct cost budget of [illegible]200. Results for the 95 percent confidence level are shown below in Figure 2b-2, a diagram analogous to Figure 2b-3. The results may be looked at

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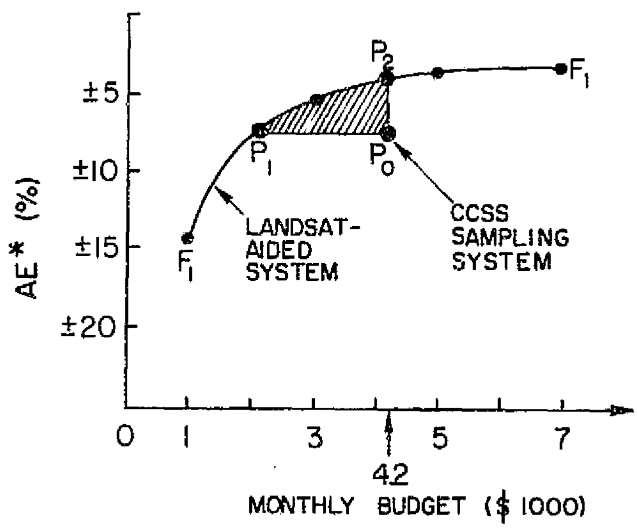
from two viewpoints: either <u>cost savings</u>, or <u>increased precision</u>.

Figure 2b-3 permits a cost comparison of the two production systems at many levels of effectiveness. One production possibility of the existing system is represented by point P_0 at the $4,200 monthly direct cost budget level. Point P_1 identifies an output of similar precision and accuracy in the LANDSAT-based system. The cost advantage per snow survey month is represented by the horizontal distance between P_0 and P_1. In this case, the LANDSAT-based system shows approximately a $2,300 savings over the existing system of snow water content estimation. Extrapolated over the full range of survey months, this would imply a savings of around 50 percent over the existing annual snow survey budget for the Feather River Basin.

FEATHER RIVER BASIN 1973



* ALLOWABLE ERROR AT 95% LEVEL OF CONFIDENCE

FIGURE 2B-3 COST-CAPABILITY COMPARISON OF SNOW WATER CONTENT SAMPLING SYSTEMS

Advantages of the LANDSAT-aided system are also apparent on the capability or effectiveness side. At the $4,200 budget level, the proposed snow water content estimation produced results approximately 1.8 times more precise than the existing system.

In general, the LANDSAT-aided system yielded relatively precise estimates of total watershed snow water content. For a $4,200 monthly budget, this approach estimated true basin snow water content to within ± 3.6% ninety-five times out of a hundred. The precision of basin snow water content estimates could be improved still further by using techniques that increase the correlation of orbital to ground snow water content estimates. Smaller image sample units, more environment-specific snow class interpretations, and automatic processing of satellite digital data are some of the more promising of these techniques.

2b.2.3.4 DISCUSSION

Without question, the foregoing results appear very promising. Extreme care nevertheless should be exercised in interpreting them. Just as the snow water content estimation methodology is built on a first-case model, so that evaluation rests on a foundation of preliminary cost estimates and approximations. Quantitative statements, in other words, generally imply some sort of inherent qualitative judgments. A perceptive interpreter will automatically employ this caveat when examining cost and precision figures.

Even when these findings are treated as tentative and first-case results, however, it is difficult to overlook the magnitude of the cost and capability improvements demonstrated by the LANDSAT-aided snow water content estimation system under study. The results could be described as an impelling reason to continue the activities proposed in Section 2b.2.2. Additional research now in progress and planned for the forthcoming year is expected to test and verify many elements of the cost-effectiveness analysis performed to date. Future work in developing water content estimation methodology will be accompanied by corresponding refinements in evaluation procedures.

2b.3 REMOTE SENSING-AIDED EVAPOTRANSPIRATION ESTIMATION SYSTEM

2b.3.0 INTRODUCTION

Water vapor is the principal participant in the many energy exchanges taking place in the atmosphere. These energy exchanges are responsible for the weather phenomena which serve as important links connecting the various phases of the hydrological cycle.

Quantification of the water flux mechanisms, viz. evaporation and evapotranspiration (which includes active plant water loss), is of importance in many scientific fields. They form one of the main components of the water budget, knowledge of which is indispensable for the solution of numerous water management problems. Reliable evaporation data are required for planning, designing and operating reservoirs, ponds, shipping canals and irrigation and drainage systems. Data on evapotranspiration are useful for estimating irrigation requirements, rainfall disposition, safe yield of ground water basins, water yields from mountain watersheds, stream flow depletion in river basins, and in vegetation management for fiber production. Evapotranspiration is especially important in arid zones where water must be used in the most efficient way possible. In addition, knowledge of the water requirement of crops depends partly on an accurate determination of the loss of water by evapotranspiration from cultivated fields.

In view of the overriding importance of evapotranspiration to accurate basin water yield estimation and to other water consumptive use determinations, any cost-effective, precise evapotranspiration estimation system would be of significant utility to a water manager. Remote sensing techniques may provide the key to such a system's data requirements. Its timely, spatial, and relatively inexpensive nature when combined with other conventional meteorological data can potentially give rise to accurate, location-specific estimates of evapotranspiration.

Moreover, current water yield estimation procedures such as the California River Forecasting Center model can incorporate evapotranspiration estimates. It is therefore the purpose of this section to lay the foundation for a remote sensing-aided methodology for accurate and efficient watershed evapotranspiration estimation.

2b.3.0.1 Objectives

One objective of the current NASA Grant water supply in the Feather River Watershed is to develop a general evapotranspiration estimation procedure utilizing remote sensing data. This method will be part of the larger water loss estimation procedure designed to produce more precise estimates of water yield. Additionally, the evapotranspiration estimates

will be applied to more efficient wildland vegetation management, including vegetation establishment and silvicultural treatment.

2b.3.0.2 Test Site Location

Similar to the case of snow areal extent methodology development, it will be efficient for initial tests of the technique to be performed on the Spanish Creek Watershed. Application of the estimation procedure to the entire Feather River Watershed is to be considered later.

2b.3.0.3 Definition

Evaporation may be defined as the transfer of water vapor from a non-vegetative surface on the earth into the atmosphere. Evapotranspiration is the combined evaporation from all surfaces and the transpiration of plants. Except for the omission of a negligible amount of water used in the metabolic activities, evapotranspiration is the same as the "consumptive use" of the plants. The fact that the rate of evapotranspiration from a partially wet surface is greatly affected by the nature of the ground leads to the concept of potential evapotranspiration. Penman (1956) defines potential evapotranspiration as "the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short in water." Recently, Pruitt (1960) designated the term "potential maximum evapotranspiration" to describe the situation when advected (horizontal movement of energy through the atmosphere surrounding the plant) energy is present.

2b.3.1 MATERIALS & METHODS

A multistage, multiphase sample design will be utilized to estimate watershed evapotranspiration water losses. Basically, there are three increasingly resolved levels of information, each of which is sampled. The first level is composed of satellite and topographic data. Vegetation, terrain and meteorological types of information are defined for a convenient base resolution element, in this case a small group of LANDSAT pixels. Based on this information associated with each base resolution element, an estimate of evapotranspiration is made for that location. The appropriate evapotranspiration equations, defined as Level I models, must be able to perform adequately on this "least resolved" information available from the first data level. Adequate performance is defined as a generation of evapotranspiration estimates strongly correlated to actual ground-measured or ground-based estimates of evapotranspiration.

After an estimate of evapotranspiration has been made for each basin resolution element, the resolution elements (here 3 x 3, 4 x 4, or 5 x 5 blocks of pixels) are grouped into primary sampling units (PSU's). Based upon the variability among PSU's, a sample of these units will be selected within each stratum for further sampling. Selection may be with probability

to estimated size of evapotranspiration within given PSU's. Within each PSU selected, a series of secondary sampling units (SSU's) will be defined and photographed at large scale with light aircraft. The photographic SSU data along with nearby snow course and ground station calibrated meteorological satellite data will provide the second level of information resolution.

At the SSU stage of the sampling design, much more specific information concerning local vegetation canopy, soil, and locate climatic conditions will be available as opposed to that obtainable from information at level one. Thus level two evapotranspiration models employing more data types and more refined data will used to generate evapotranspiration estimates for each PSU.

A sample of two of the SSU's per PSU selected will then be randomly (equal and/or unequal probability) chosen for further analysis on the ground. For each of these SSU's selected, detailed ground measurements will be made of vegetation canopy geometry, color etc. as well as of soil and litter-organic debris conditions. The detailed data from this third level of information will then drive evapotranspiration prediction models. Since estimates of evapotranspiration will be for the entire ground area of the SSU photo plot, this third stage unit (TSU) will actually comprise a double sample of the SSU's. Figure 2b.4 summarizes the sampling concepts and terminology in the preceding discussion.

The full watershed estimate of evapotranspiration can then be developed by first using the ground based evapotranspiration estimate to calibrate the SSU estimate derived from photo data. The calibrated SSU estimates can then be expanded to the PSU stage by utilizing the SSU selection weights developed earlier. Finally, PSU evapotranspiration estimates can be expanded, each over the appropriate stratum, and then to the entire watershed by applying the PSU selection weights (proportion of evapotranspiration in the given PSU relative to all other PSU in the watershed) originally calculated. In this way, a cost-effective combination of an increasingly smaller sample of more precise and more expensive information levels can be utilized to give basin-wide watershed estimates.

Figure 2b.5 shows the multistage estimation equation that will be used to combine data from levels I, II, and III in order to generate an estimate of watershed-wide evapotranspiration. Term definitions are summarized in Table 2b.4. The procedure defined by the ET equation in Figure 2b.5 is as follows. First the ground-based estimate of evapotranspiration, y_{ij}, for the j^{th} SSU of the i^{th} PSU is inflated by division with p_{ij} (the proportion of evapotranspiration estimated from level II data to occur in the j^{th} SSU of the i^{th} PSU relative to the sum of ET determined for all photo SSU's in the i^{th} PSU). After multiplication by the ratio of the average segment area (A_i) to its corresponding plot area (a), this inflated ground ET value represents an estimate of

FIGURE 2B.4 - EVAPOTRANSPIRATION SAMPLE DESIGN TERMINOLOGY

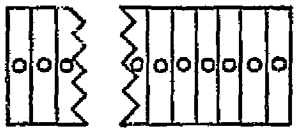
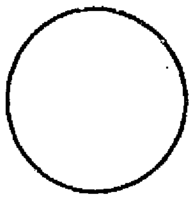
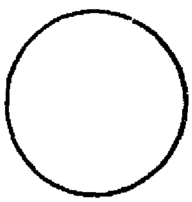
Information Level	Sample Unit	Sample Design Level	Comments
1	PSU 	STAGE I Multistage portion of sample design	All PSU's in watershed have evapotranspiration estimates made based on a summation of evapotranspiration estimates for LANDSAT resolution elements occupying each PSU. A sample of the PSU's is selected for further sampling
2	PHOTO SSU 	STAGE II PHASE 1 Multiphase or double sample portion of sample design	All SSU's within a selected PSU have evapotranspiration estimates made based on surface characteristics interpreted from the photography
3	GROUND SSU 	PHASE 2	Ground measurements resulting in ground-based evapotranspiration estimates are made for a sample of the photo SSU'

FIGURE 2B.5

Multistage E T Estimation Equation and Corresponding Sample Frame

$$ET = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{p_i} \left[\frac{1}{n_i} \sum_{j \epsilon \{D\}} \frac{A_i}{a} \times \frac{y_{ij}}{p_{ij}} \right]$$

$$p_i = \frac{ET_i}{\sum_{i=1}^{n} ET_i}$$

$$p_{ij} = \frac{ET_{ij}}{\sum_{j \epsilon \{D\}} ET_{ij}}$$

ET_i = ET based on level I data

ET_{ij} = ET based on level II data

$y_{ij} = ET_{ij}^{*}$ = ET based on level III data

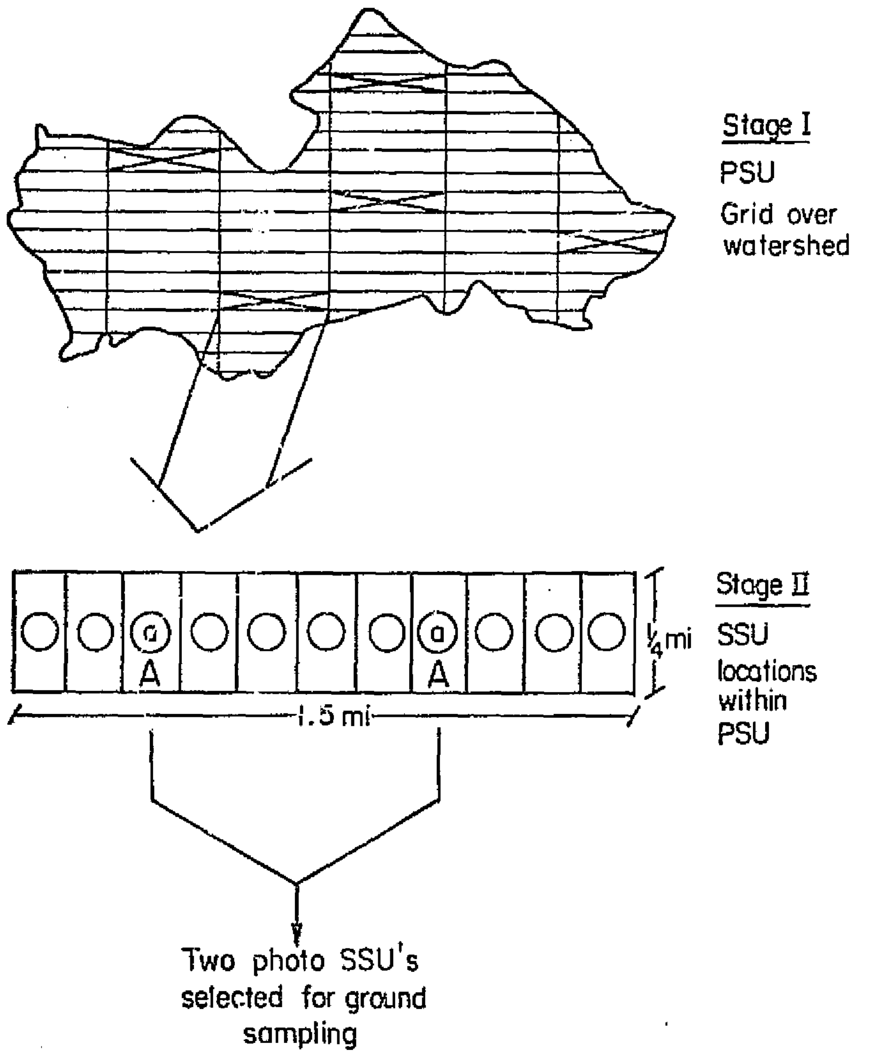


TABLE 2b.4 Description of Multistage ET Estimation Equation in Figure 2b

n = number of PSU's sampled (5).

p_i = probability of selection of the ith PSU

n_i = number of SSU's selected within ith PSU (2)

$JE\{D\}$ = the set of SSU's selected in each sampled PSU

A_i = area of the section within which SSU is located

a = area of SSU

Y_{ij} = ground ET estimation for the jth SSU of the ith PSU

p_{ij} = probability of selection of jth SSU for ground measurement

ET = average evapotranspiration estimate for the entire watershed

total evapotranspiration for the i^{th} PSU.

These PSU ET estimates are made for each ground measured SSU in the i^{th} PSU. Ground visited SSU's in a given subsampled PSU, are defined to compose the set D. Summing over these ET estimates for each SSU in the set D and then dividing by, n_i, the number of SSU's in set D of the i^{th} PSU, then gives an average estimate of PSU evapotranspiration. The steps just described are indicated within the bracketed expression of the ET equation in Figure 2b.

Once an average evapotranspiration estimate has been derived from level I and level II data, for each of the small number of PSU's subsampled, then each such value must be inflated to a watershed-wide ET estimate. This is done, as shown in Figure 2b.5 by multiplying the bracket quantity by p_i. There p_i represents the proportion of evapotranspiration in the i^{th} PSU based on level I information relative to the sum of evapotranspiration from all PSU's in the watershed. The watershed-wide evapotranspiration estimates thus gained for each PSU selected for subsampling are then summed. This sum is next averaged by dividing by n, the total number of PSU's selected for subsampling. The result is the average watershed-wide estimate of evapotranspiration.

Sampling theory allows a derivation of an estimate of variance for the above watershed ET estimate. Multiplying the result standard error by an appropriate Student's-t value gives a confidence interval half-width (a statistical statement of estimate precision) to be associated with the estimate.

The true value of evapotranspiration from the watershed is then expected to lie within plus or minus the confidence interval half-width of the ET estimate a given number of times out of a hundred (e.g. 90) with specified confidence probability (e.g. .95).

2b.3.1.1 Recommended Models for Level I

These models will utilize the first level of information resolution and provide the first estimate of ET for the appropriate PSU's.

Empirical and semiempirical formulas will be applied in this level. These formulas will be modified based on the measured values of evaporation data in the watershed of interest. The input for these models come primarily from LANDSAT, environmental (meteorological) satellites, ground meteorological stations, and digital topograhic data. The variables to be derived from these data for the above models are surface temperature (daily average, minimum, maximum), all radiation components, relative humidity, precipitation, and cloud cover. The models based on the following equations are being considered for this level.

Jensen and Haise Equation

The Jensen and Haise (1963) equation uses total short-wave solar radiation (R_s), (expressed in inches of evaporation equivalent) as its climatic factor and a dimensionless crop coefficient (ET/R_s) to reflect the effect of crop type and stage of growth, as well as climatic factors not accounted for by solar radiation. Thus:

$$ET_p = (ET/RS)\ RS$$

In addition, the equation

$$ET_p = (0.014\ T - 0.37)\ R_s$$

is presented, where ET_p is potential evapotranspiration in inches, T is mean daily temperature in °F, and R_s is total solar radiation in inches of evaporation equivalent.

Hargreaves Equation

Hargreaves (1956) developed the equation

$$E_v = 0.38\ (1\text{-}0.1H_n)\ D\ (T\text{-}32)$$

Where E_v is Class A pan evaporation in inches, D is a monthly daytime coefficient defined as the ratio of the daylength for the month to 12 hours H_n, is the monthly relative humidity at noon (humidity at 1:00 P.M. can also be used satisfactorily), and T is the mean monthly temperature in °F.

Mathison (1963) plotted relative humidity against temperature differences. The line of best fit can be expressed by the equation:

$$H_n = 113 - 2.5\ (\Delta T)$$

in which ΔT is the difference between the mean maximum and minimum temperature in °F.

$$\Delta T = T\ (\text{max.}) - T\ (\text{min.}).$$

All the formulas in this method are based on 60 miles of wind movement per day. Evaporation increases or decreases about 9% with each 30 miles per day increase or decrease in the wind.

Blaney - Criddle Equation

Blaney and Criddle (1950) developed the equation

$$e = k\ (tp)\ (114\text{-}h)$$

where e is monthly evaporation in inches, k is a monthly coefficient, t is the mean monthly temperature (°F), p is the monthly percentage of day-time hours in the year, and h is the mean monthly relative humidity in percent.

Turc Equation

Turc used the equation

$$Cu = \frac{P}{\left(0.9 + \frac{P^2}{L^2}\right)^{\frac{1}{2}}}$$

in his method where $L = 300 + 25T + 0.05\,T^3$. T is the mean annual temperature in °C, p is annual precipitation in milimeters, and Cu is consumptive use in milimeters.

2b.3.1.2 Recommended Models for Level II

The basis for the evapotranspiration models to be applied to the second level of information resolution is that of energy conservation, which is a proven law of thermodynamics. For this level, the energy-balance method will be combined with other methods for consideration of vegetation canopy effects and advected energy processes. The objective of the model applied at level II will be to capitalize on vegetation canopy, geometry-composition, and other surface data available from aerial photography tc provide improved evapotranspiration estimates for the appropriate photo SSU's. The following models are being examined for application:

Priestly and Taylor Model

Priestly and Taylor used the equation

$$E = \frac{\alpha}{L} \frac{(S)}{S+\gamma} (R_N - G)$$

for estimation of evapotranspiration over the surfaces where surface resistance was expected to be negligibly small. In this equation s in slope of saturation curve versus temperature, γ is psychrometric constant, R_N is net radiation, and G is heat flux into the soil. The best value of α was found to be 1.26. This estimate of α was found to be 1.26. This estimate of α is the overall mean of land and water surface.

McNaughton and Black Model

The best potential evapotranspiration relationship that was suggested by McNaughton and Black (1970) is

$$PE = \frac{1.05}{L} \frac{S}{S+\gamma} (R_N - G) + 0.17 \text{ GIL}$$

where PE is potential evapotranspiration, L is latent heat of water, s is slope of saturation curve versus temperature, γ is psychrometric constant, R_N is net radiation, G is heat flux to the soil, and GIL is gross interception loss.

Modified McIlroy and Slatyer

The following equation was used by McIllroy and Slatyer to estimate actual evapotranspiration (E).

$$E = \frac{E(pot)}{1 + \frac{\gamma}{S+\gamma} \times \frac{h}{h_i}}$$

where γ is psychrometric constant, s is slope of saturation vapor pressure curve versus temperature, h, is transfer coefficient, h_i is molecular diffusion of water vapor through stomata, and $\frac{h}{h_i}$ represents the canopy effect on the amount of actual evapotranspiration. This equation will be modified to use some other terms for the canopy effect.

Linacre Model

A semi-empirical method of evapotranspiration is derived by Linacre (1967) through the combination of Penman's method and solar radiation equations. Linacre considered the forest canopy as impeding the loss of water by means of two resistances. The canopy resistance, r_c, which is a function of canopy structures and its properties, and aerodynamic resistance, r_a, which is a function of the canopy - atmosphere interface. The combined equation is:

$$LE = \frac{\Delta Q_n + C_p \cdot \rho \cdot \frac{s}{r_a}}{\Delta + \gamma + \gamma \frac{r_c}{r_a}}$$

in which Q_n is the difference between downwards and upwards radiation fluxes; C_p is the specific heat of air at constant pressure; ρ is the air density; γ is psychrometric constant; s is saturation deficit, and Δ is the change of water vapor pressure with temperature in ambient conditions.

The variables to be estimated for input to the level II models are much more canopy and ground surface specific than those required for level one. In general, input variables to be applied in level II must be determined more precisely and more frequently as well. Data requirements include temperature, humidity, and wind value profiles in the soil surface-vegetation zone. Wind friction velocity, rainfall, ground cover, and topograhic data may also be considered. These canopy data requirements will be fulfilled in large part through large scale photographic measurements collected from photo second stage sampling units and calibrated by corresponding ground data. Canopy-top meteorological data will be obtained as in level I, viz. through meteorological satellite data calibrated by ground station information and by microclimatic functions extrapolating satellite and ground data values to SSU's of interest. Vertical meteorological variable profiles within the canopy will be generated from canopy-top data according to canopy geometry functions.

2b.3.1.3 Recommended Models for Level III

The third information resolution level in the remote sensing-aided evapotranspiration estimation system will allow application of the practical as well as the most sophisticated models. The approach will be to select and develop those evapotranspiration estimation equations which are most rational and physical in terms of the actual processes involved. A combination of empirical, energy balance, and aerodynamic methods will be examined for this level.

In addition, a new operational model will be developed and tested against other techniques. It will be based on a combination of methods using radiation energy and temperature as primary variables (e.g. Jensen and Haise equation) and on methods considering vegetation canopy effects and aerodynamic resistance (e.g. Priestly and Taylor equation, McNaughton and Black equation). This new model will be constructed so as to take best advantage of the data gained through remote sensing and ground sampling.

2b.3.2 RADIATION

Of the tremendous quantity of radiant energy emitted by the sun, only a very small portion is intercepted by the earth and its atmosphere. This small portion is the ultimate source of the earth's energy. This amount of incident radiation is known as the solar constant which is defined as the intensity of solar radiation received on a unit area of a plane normal to the incident radiation at the outer limit of the earth's atmosphere with the earth at its mean distance from the sun. The value of the solar constant is generally taken to be 1.94 Langleys per minute which is based on the 1913 Smithsonian standard scale. Recently there has been evidence that this value is too low and a value of 2.00 ly/min has been offered (Miller, 1951).

The portion of the solar radiation which actually reaches the earth's surface depends upon the transparency of the atmosphere. Some of the incident solar radiation is reflected, some scattered, and some absorbed by the atmosphere. In the absence of clouds these amounts are relatively small and quite constant. The atmospheric transmission coefficient varies from about 80 percent at the time of the winter solstice to about 85 percent at the time of the summer solstice. Atmospheric transmission coefficients are based on the total insulation received at the earth's surface and include both the direct and difussed radiation.

By far the largest variation (in the portion of solar radiation transmitted by the atmosphere) are caused by clouds. The transmitted radiation varies with type, height, density, and amount of clouds. The quantitative consideration will be discussed later. Since clouds are such a powerful controlling factor in radiative heat exchange, other minor factors such as humidity of the air are often ignored.

Similar to the cloud effects, the forest canopy exerts a powerful controlling influence on net allwave radiation exchange in evapotranspiration. However, the forest canopy has a different effect than that of clouds, particularly with respect to shortwave radiation. While both the clouds and trees restrict the transmission of insulation, clouds are highly reflective, while the forest canopy absorbs much of the insulation. Consequently, the forest canopy tends to be warmed and in turn gives up a portion of the energy for evapotranspiration.

2b.3.2.1 Definitions

Total incoming solar radiation (I & H) is defined as the direct (I) and diffused (H) shortwave radiation reaching the ground through the atmosphere. Some of this incident radiation is reflected back to the atmosphere (R), which is called reflected radiation, and the rest is absorbed by objects on the earth's surface. Part of the absorbed radiation is dissipated to the atmosphere as longwave radiation (G). In turn, a portion of this dissipated longwave radiation is absorbed by the clouds and atmosphere particles and part of it is returned to the ground (A). This returned longwave radiation from the atmosphere to the ground (A) is called atmospheric radiation. The difference between upgoing (G) and atmospheric (A) longwave radiation may be defined as the net longwave radiation. Net radiation (Q_n), as it is shown in the following equation, is the sum of net shortwave radiation (I+H-R) and net longwave radiation (-G+A).

$$Q_n = (I+H+R) + (A-G)$$

The reflection or albedo is the ratio of reflected to the incident radiation, usually expressed as a percentage. Table 2b.5 gives albedos for the total range of solar radiation and in some cases for the

visible electromagnetic range only. The figures given in this table illustrate what can be observed directly from an airplane. The sea appears darkest, relative to white strips of surf and sand dunes. Woods show up darker than fields, and snow covered areas are light. One can see here how the absorption capacity for incident solar radiation varies and how this affects the whole heat economy and therefore evaporation and evapotranspiration. Albedo is influenced not only by the nature of a surface, but also by its moisture content at any time, i.e., wet surfaces appear darker than dry surfaces.

2b.3.2.2 Determination of Net Radiation Flux

The net radiation flux Qn, may be calculated from the equation

$$Q_n = (1=\alpha) \quad Q_s - |Q_{nL}|$$

where is albedo, Q_s is the total flux of shortwave radiation from the sun and the sky, and Q_{nL} is the net upward flux of longwave radiation computed as follows:

$$Q_{nL} = Q_{Ld} - Q_{Lu}$$

$$Q_{Ld} = 0.971 \times 10^{-10} \, T_k^4 - 0.245 \ (\text{cal. cm.}^{-2} \text{min}^{-1})$$

$$Q_{Lu} = 0.813 \times 10^{-10} \, T_k^4 \ (\text{cal. Cm}^{-2}. \ \text{min}^{-1})$$

where Q^*_{nL} is the net flux of longwave radiation in cloudless conditions, Q_{Ld} is the downward flux of longwave radiation from a clear sky (derived from the formula of Swinbank, 1963, (T_k) is the ambient temperature in degrees of Kelvin and Q_{Lu} is the upward flux of longwave radiation from a surface with unit emissivity (Linacre, 1968). Then

$$Q_{nL} = Q^*_{nL} \left[b + (1-b) \frac{n}{N}\right]$$

where there are n hours of actual sunshine in a daylength of N hours. The term b has been taken to be either 0.10 (Penman, 1948), 0.20 Kramer, 1957), 0.24 (Impens, 1963), or 0.30 (Fitzpatrick and Stern, 1965); a value of 0.20 may be adopted as a compromise (Linacre, 1968). Combining these equations

$$Q_{nL} = (-0.245 + 0.158 \times 10^{-10} \, T_k^4) \ (0.2 - 0.8 \, \frac{n}{N}) \ \text{in cal. Cm}^{-2}. \ \text{min}^{-1}$$

$$Q_n = (1-\alpha) \, Q_s - |(-0.245 + 0.158 \times 10^{-10} T_k^4) \ (0.2 + 0.8 \, \frac{n}{N})|$$

TABLE 2b.5

Stand	Albedo Percent	Source
Fresh snow cover	75-95	Geiger
Dense cloud cover	60-95	"
Old snow cover	40-70	"
Clean firn snow	50-65	"
Ice, sparse snow cover	69	Smithsonian table
Clean glacier ice	20-50	"
Light sand dunes, surf	30-46	Geiger
Sandy soil	15-40	"
Meadow and fields	12-30	"
Meadow, low grass	15-25[a]	Smithsonian table
Field, plowed, dry	20-25[a]	"
Densely built-up area	15-25	Geiger
Woods	5-20	"
Dark cultivated soil	7-10	"
Douglas-fir	13-14	Avery
Pine	14	Brooks
Conifers	10-15	Budyko
Deciduous forest, fall	15[a]	Krinov
Deciduous forest, summer	10[a]	"
Coniferous forest, summer	8[a]	"
Coniferous forest, winter	3[a]	"
Meadow dry grass	10[a]	"
Field Crops, ripe	15[a]	"
Spruce	8-9	Baumgartner
Earth roads	3[a]	Krinov
Black top roads	8[a]	Sewing Handbook
" " "	9[a]	Krinov

Stand	Albedo Percent	Source
Concrete road	35[a]	Krinov
Buildings	9[a]	"
Mountain tops, bare	24[a]	"
Clay soil dry	15[a]	Sewing Handbook
Clay soil wet	7.5[a]	"
Clouds, stratus overcast, 0-500 feet thick	5-63	"
Clouds, stratus overcast, 500-1,000 feet thick	31-75	"
Clouds, stratus overcast, 1,000-2,000 feet thick	59-84	"
Clouds, dense, opaque	55-78	"
Clouds, dense, nearly opaque	44	"
Clouds, thin	36-40	"
Clouds, stratus, 600-1,600 feet thick	78	"
Clouds, stratocumulus overcast	56-81	"
Clouds, altostratus, occasional breaks	17-36	"
Clouds, altostratus, overcast	39-59	"
Clouds, cirrostratus and altostratus overcast	49-64	"
Clouds, cirrostratus overcast	44-50	"

Whole earth: From measurements on the bright and dark portions of the moon, Danjon[b] has calculated the albedo of the earth in the visible portion of the spectrum at 39 percent. Fritz[c] has extended the calculation to include infrared and ultraviolet radiation, obtaining a total albedo of the earth of 35 percent. Baur and Philipps[d] have calculated the total albedo to be 41.5 percent

[a]visual albedo

[b]Danjon, A., Ann. l'Obs. Strasbourg 3, No. 3, 1936, P. 139

[c]Fritz, S., Bull. Amer. Meteorol. Soc., Vol. 29, 1948, p. 303; Vol. 31, 1950, p. 251; Journ. Meteorol., Vol. 5, 1949, p.277

[d]Baur, F., and Philipps, H., Gerl. Beitr. Geophys., Vol. 42, p.160

Table 2b.6 Published values of the Factors c and d in equation (11)

Source (1)	Location (2)	Latitude (3)	Period of Means (4)	c (5)	d (6)	c+d (7)	$\bar{c}$ (8)	$\bar{d}$ (9)	$\overline{c+d}$ (10)	Latitude (11)
Black et al (1954)	Stockholm, Fairbanks	59,65°N	month	0.22	0.52	0.74				
Monteith (1966)	Lerwick	60°N	day	0.23	0.56	0.79				
Penman (1948)	Rothamsted, U.K.	52°N	month	0.18	0.55	0.73				
Baier and Robertson (1963)	Canada	52°N	day	0.25	0.62	0.87	0.21	0.55	0.76	54°
Black et al. (1954)	Kew, U.K.	51°N	month	0.19	0.57	0.76				
Van Wijk (1963)	Gembloux	51°N	month	0.15	0.54	0.69				
" " "	Versailles	49°N	month	0.23	0.50	0.73				
Tanner and Pelton (1960)	Wisconsin	43°N	-	0.18	0.55	0.73				
de Villele (1965)	El Aouina	37°N	10 days	0.28	0.43	0.71				
de Vries (1958)	Deniliquin	36°S	day	0.27	0.54	0.81				
Damagnez (1963)	Tunisia	35°N	-	0.16	0.59	0.75	0.23	0.53	0.76	36°
Prescott, (1940)	Canberra	35°S	month	0.25	0.54	0.79				
Black et al (1954)	Dry Creek	35°S	month	0.30	0.50	0.80				
Page (1961)	Capetown	34°S	month	0.20	0.59	0.79				
Glover (1958)	Durban	30°S	day	0.25	0.50	0.76				
Yada (1959)	Delhi	29°N	week	0.31	0.46	0.77				
Glover (1958)	Pretoria	26°S	day	0.25	0.50	0.75	0.28	0.49	0.77	24°
" "	Windhoek	23°S	day	0.26	0.52	0.78				
Page (1961)	Tananarive	19°S	month	0.30	0.48	0.78				
Smith (1964)	Jamaica	18°N	day	0.31	0.49	0.80				
Fitzpatrick (1967)	Kimberley	16°S	day	0.33	0.43	0.76				
Cackett (1964)	Central Africa	15°S	-	0.32	0.47	0.79				
Page (1961)	Dakar	15°N	month	0.10	0.70	0.80	0.26	0.50	0.76	13°
Yada (1959)	Madras	13°N	week	0.31	0.49	0.80				
Davies (1965)	Kano	12°N	month	0.26	0.54	0.80				
Smith (1964)	Trinidad	11°N	day	0.27	0.49	0.76				
Stanhill (1963)	Benin City[a]	7°N	week	0.26	0.38	0.64				
Davies (1965)	Accra	6°N	month	0.30	0.37	0.67				
Black et al (1954)	Batavia etc.	6°S	month	0.29	0.29	0.58				
Page (1961)	Leopoldville	4°S	month	0.21	0.52	0.73				
" "	Singapore	1°N	month	0.21	0.48	0.69				
Glover (1958)	Kabete, Kenya	1°S	10 days	0.24	0.59	0.83	0.25	0.44	0.69	3°
Page (1961)	Stanleyville	1°N	month	0.28	0.40	0.68				
Rijks (1964)	Kampala	0°	day	0.24	0.46	0.70				
			Mean Values	0.245	0.507	0.752				
Hounam (1963)	Australia	12-43°S	month	0.26	0.50					
Davies (1965)	West Africa	5-15 N	month	0.19	0.60					
Black et al (1954)	general	-	month	0.23	0.48					
Page (1961)	tropics	-	month	0.23	0.52					
Turc (1961)	general	-	month	0.18	0.62					

[a]Davies (1965) gave 0.28 and 0.33 for c and d respectively

SOURCE: Linacre, 1968

TABLE 2b.7. Available Meteorological Data in Ground Meteorological Stations within the Spanish Creek Watershed.

Station	lat	lat	UTM($x10^3$) X	Y	Dates of data
Quincy	120°57'	39°55'	675.63	4422.57	72*, 75† & 75‡
Greenville	120°56'	40°08'	675.19	4445.11	72* & 75†
Boulder Creek	120°37'	40°12'	703.25	4452.34	72* & 75†
Mohawk	120°38'	39°47'	702.62	4406.53	72* & 75†
Camel Peak	121°06'	39°43'	662.84	4398.22	72* & 75†
Smith Peak	120°32'	39°52'	711.32	4415.75	72* & 75†

* = Wet bulb temperature, dry bulb temperature, daily temperature relative humidity, precipitation, and wind speed and direction

† = Daily average temperature, relative humidity, precipitation, and wind speed and direction.

‡ = Wet bulb temperature, dry bulb temperature, daily average temperature, evaporation, precipitation, cloud cover, and day length.

Table 2b.6 Published values of the Factors c and d in equation (11)

Source (1)	Location (2)	Latitude (3)	Period of Means (4)	c (5)	d (6)	c+d (7)	$\bar{c}$ (8)	$\bar{d}$ (9)	$\overline{c+d}$ (10)	$\overline{\text{Latitude}}$ (11)
Black et al (1954)	Stockholm, Fairbanks	59,65°N	month	0.22	0.52	0.74				
Monteith (1966)	Lerwick	60°N	day	0.23	0.56	0.79				
Penman (1948)	Rothamsted, U.K.	52°N	month	0.18	0.55	0.73				
Baier and Robertson (1963)	Canada	52°N	day	0.25	0.62	0.87	0.21	0.55	0.76	54°
Black et al. (1954)	Kew, U.K.	51°N	month	0.19	0.57	0.76				
Van Wijk (1963)	Gembloux	51°N	month	0.15	0.54	0.69				
" " "	Versailles	49°N	month	0.23	0.50	0.73				
Tanner and Pelton (1960)	Wisconsin	43°N	-	0.18	0.55	0.73				
de Villele (1965)	El Aouina	37°N	10 days	0.28	0.43	0.71				
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Glover (1958)	Pretoria	26°S	day	0.25	0.50	0.75	0.28	0.49	0.77	24°
" "	Windhoek	23°S	day	0.26	0.52	0.78				
Page (1961)	Tananarive	19°S	month	0.30	0.48	0.78				
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Yada (1959)	Madras	13°N	week	0.31	0.49	0.80				
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Stanhill (1963)	Benin City[a]	7°N	week	0.26	0.38	0.64				
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Page (1961)	Leopoldville	4°S	month	0.21	0.52	0.73				
" "	Singapore	1°N	month	0.21	0.48	0.69				
Glover (1958)	Kabete, Kenya	1°S	10 days	0.24	0.59	0.83	0.25	0.44	0.69	3°
Page (1961)	Stanleyville	1°N	month	0.28	0.40	0.68				
Rijks (1964)	Kampala	0°	"	0.24	0.46	0.70				
			Mean Values	0.245	0.507	0.752				
Hounam (1963)	Australia	12-43°S	month	0.26	0.50					
Davies (1965)	West Africa	5-15 N	month	0.19	0.60					
Black et al (1954)	general	-	month	0.23	0.48					
Page (1961)	tropics	-	month	0.23	0.52					
Turc (1961)	general	-	month	0.18	0.62					

[a]Davies (1965) gave 0.28 and 0.33 for c and d respectively

SOURCE: Linacre, 1968

The value of Q_s is estimated by Linacre (1967 by means of the modified Angstrom equation

$$Q_s = Q_A(c + d \frac{n}{N})$$

where Q_A is the value of Q_s above the atmosphere c and d are empirical constants, n and N are as previously defined. n is measured and values of N depend on the latitude and time of year, and are available in tables (Smithsonian Institution). The same applies to values of extra-terrestrial radiation intensity, Q_A. The values of n may be gained through remote sensing techniques. Normally, however, is measured in the field. Table 2b.6 shows the values for c and d. Linacre's equation is not exact because it doesn't allow for the varying importance of cloudiness at different times of the day.

Equation (11) has been found satisfactory by several investigators (Black, 1956, Abdel-Aziz, 1964 and Linacre, 1967). Stanhill (1965) found the estimated weekly values of Q_s were within 6% of measured values, which is comparable with the errors inherent in actual measurements.

2b.3.3 RESULTS

The topographic data collection for Spanish Creek watershed has been completed. These data include elevation contour lines, vegetation-terrain analysis mpas, slope and aspect. Based on LANDSAT data the elevation, albedo and vegetation maps of the study area are shown in Figures 2b-6, 2b-7, and 2b-8 respectively.

One of the level I ET models has been evaluated based on the ground meteorological data shown in table 2b-7. The watershed-wide distribution of temperature and relative humidity are shown in Figures 2b-9, and 2b-10 respectively. The evaporation estimation based on the temperature, relative humidity,daylength coefficient and another constant coefficient based on vegetation type and cover is shown in Figure 2b-11. Based on Blanney-Criddle model it could be primarily concluded that the major modification is needed in order to be able to apply this particular model to the watershed. The Jensen and Haise model seems more promising and will be evaluated shortly.

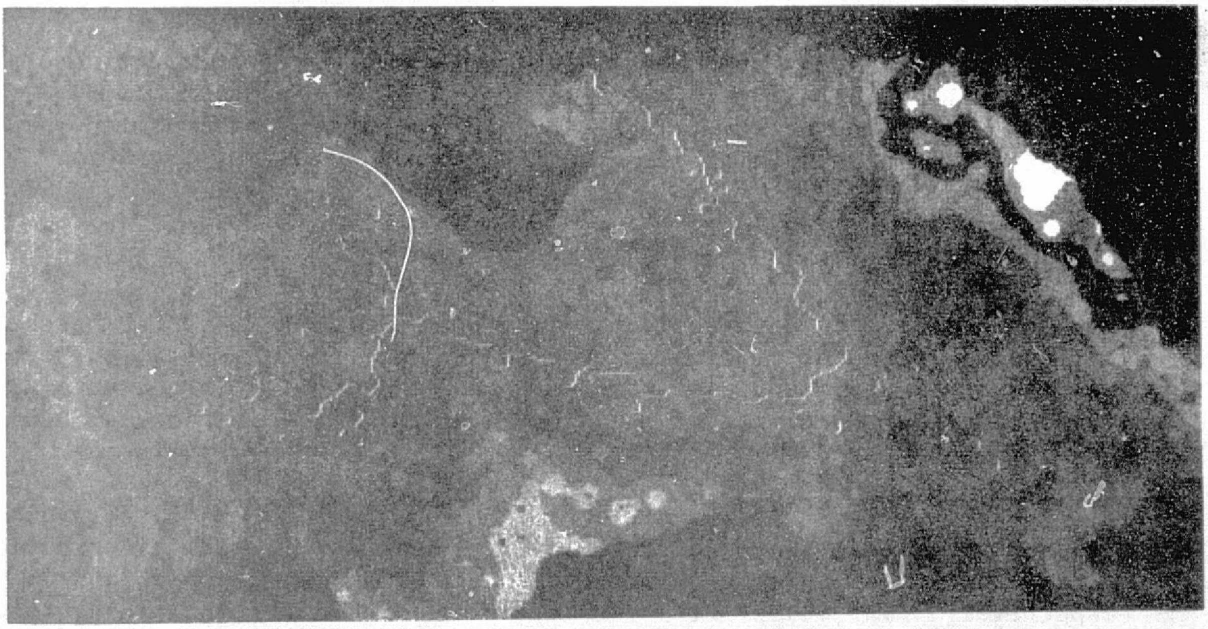


Figure 2b.6 Electronically produced display of elevation in feet (MSL) over the Spanish Creek Watershed. This elevation output was produced by computer interpretation between a sample of elevation points located on ridge tops, valley bottoms, and major changes in slope.

Blue = 3080	Yellow green = 5460
Purple = 3650	Yellow = 6030
Blue green = 4220	Red = 6600
Green = 4790	Grey = 7170
	White = 7640

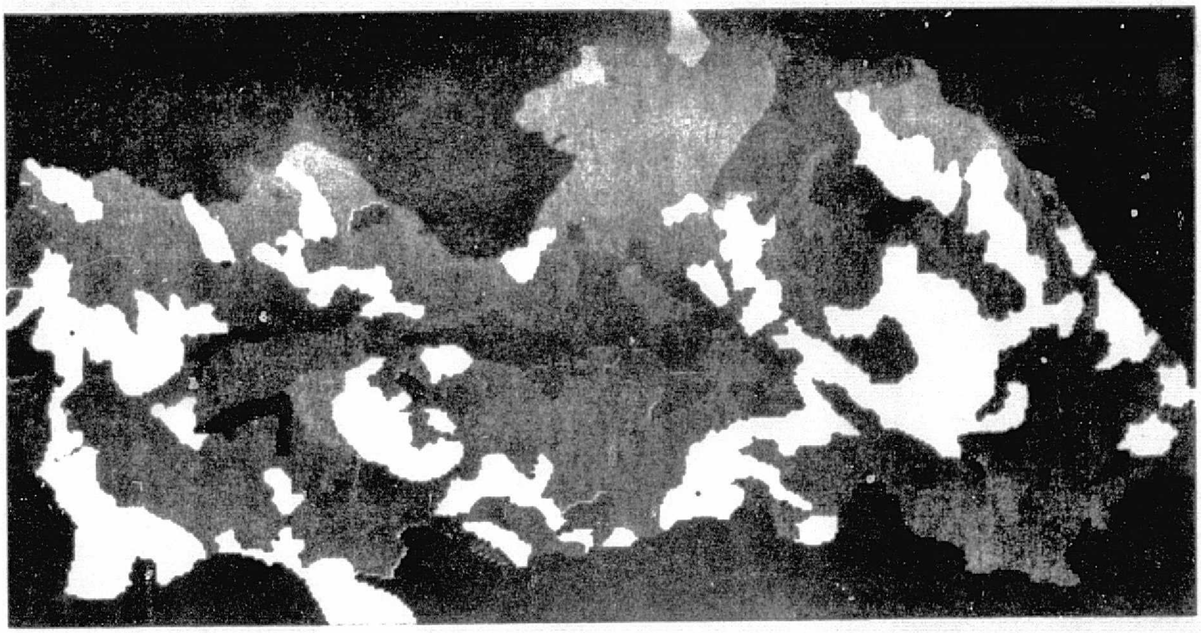


Figure 2b.7 Electronically produced display of albedo based on the manual vegetation/terrain classification of LANDSAT data over the Spanish Creek Watershed.

Blue = 5
Blue green = 7
Green blue = 9
Green = 10
Yellow = 11
Orange - 12
Gray = 13
Violet = 14
Purple = 15
White = 20

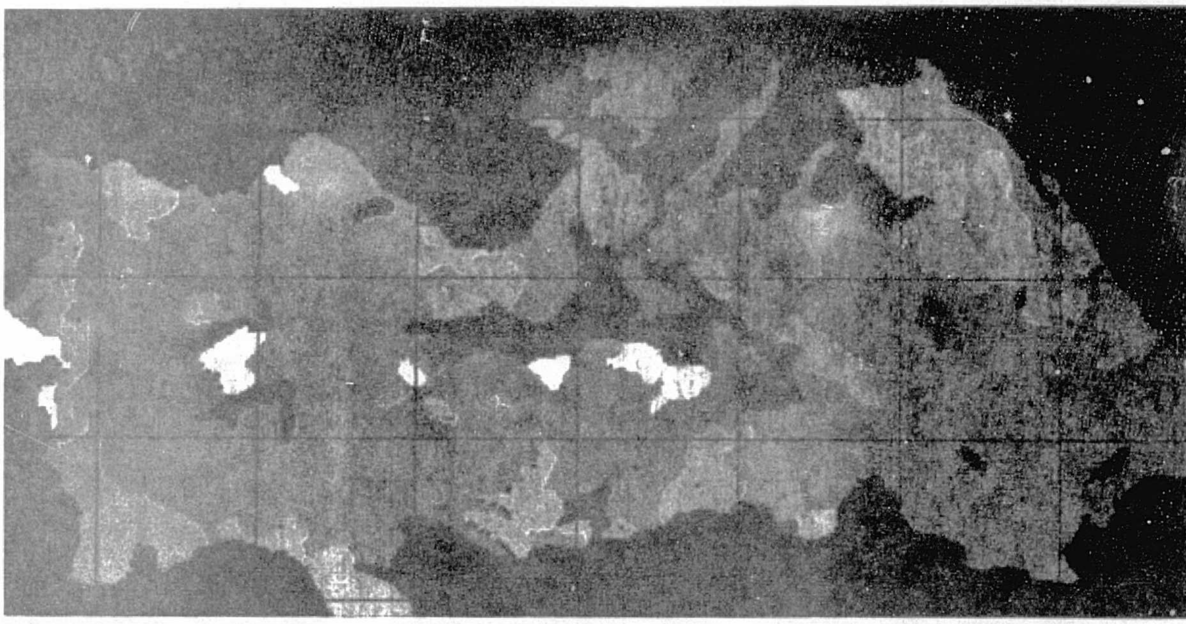


Figure 2b.8 Electronically produced display of vegetation classification over the Spanish Creek Watershed based on manual interpretation of LANDSAT data.

Blue = water
Bluish green = meadows
Blue green = brush
Dark green = east side mixed conifers
Green = red fir
Light green = lodge pole pine
Dark brown = wet site hardwood
Gray = dry site hardwood
Brown = grassland
Yellow = high altitude mixed conifer
Orange = low medium altitude mixed conifers
Purple = serpentinitic jeffery pine and incense cedar
Light purple = pervious area
White = bare ground

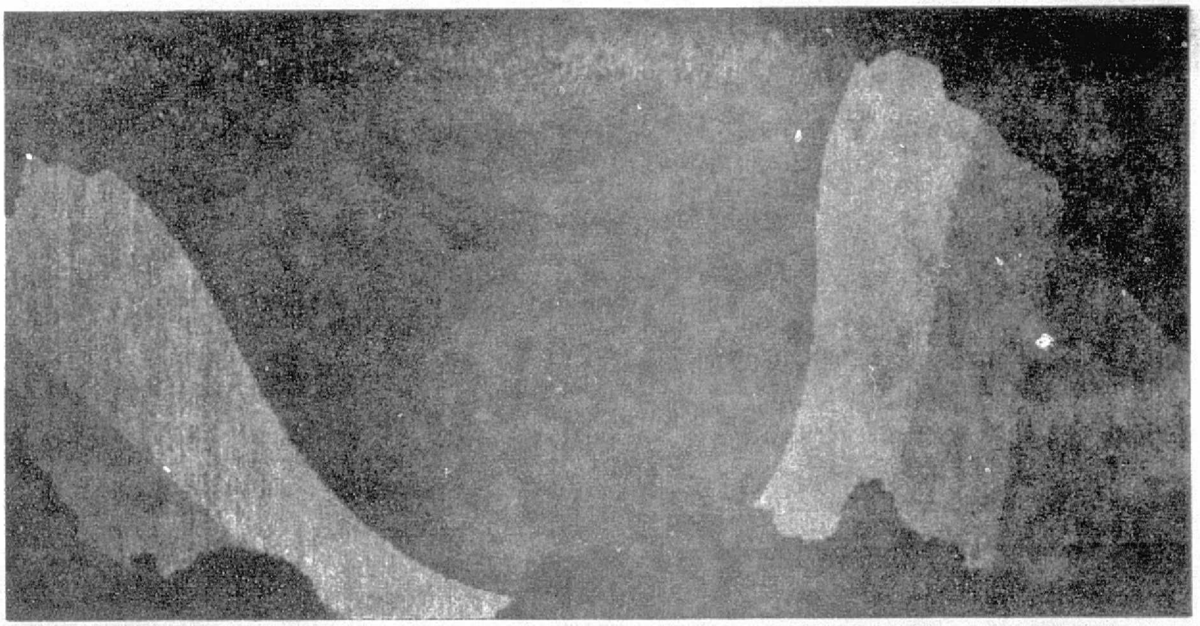


Figure 2b.9. Mean monthly temperature in F for August 1972, based on the spatial interpolation of ground meteorological data, over the Spanish Creek Watershed.

Blue = 79	Yellow = 83
Blue Green = 80	Orange = 84
Green Blue = 81	Purple = 85
Green = 82	

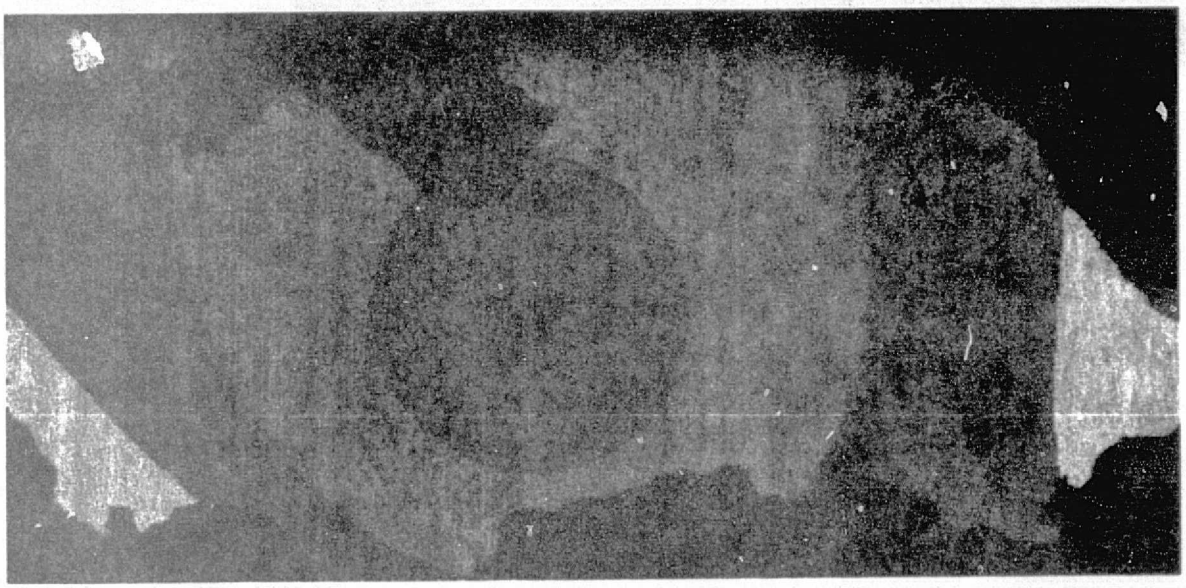


Figure 2b.10. Mean monthly relative humidity in percent for August 1972 based on spatial interpolation of ground meteorological data, over the Spanish Creek Watershed.

Blue = 16
Blue Green = 17
Green = 18
Yellow = 19
Orange = 20
White = 21

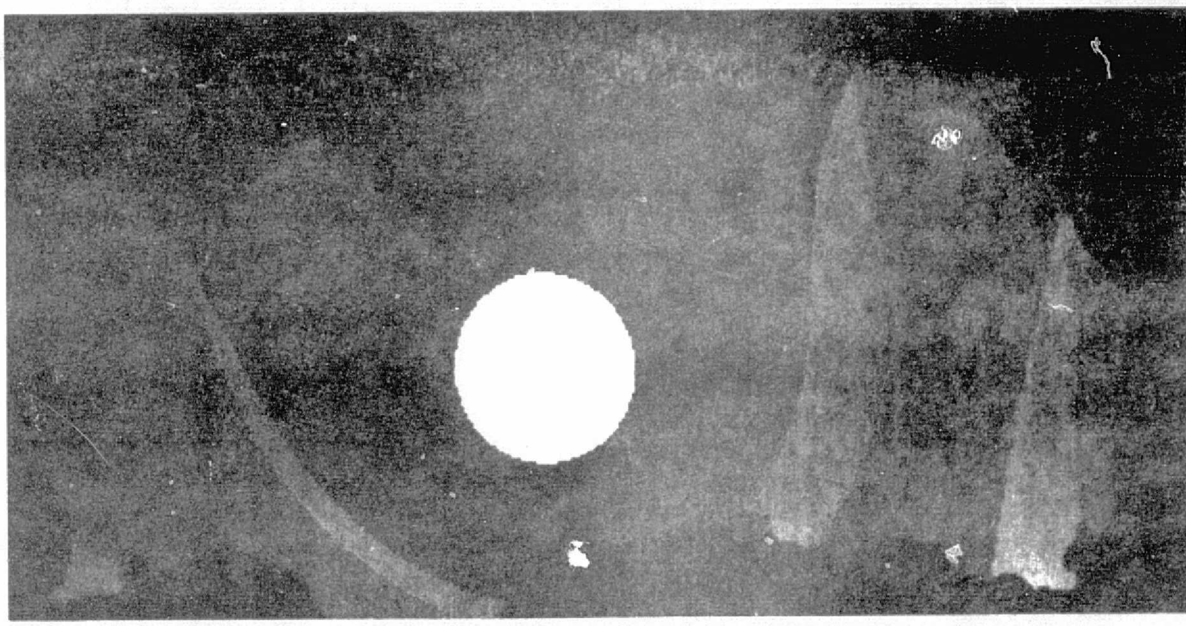


Figure 2b.11. Areal distribution of evaporation in inches of water for August 1972, Spanish Creek Watershed, based on Blanney-Criddle Equation.

Light purple = 16.13	Green = 17.10
Medium purple = 16.27	Blue Green - 17.45
Dark purple = 16.30	Dark Blue - 17.67
Darker purple - 16.47	Saturated blue = 17.84
Orange - 16.50	Opaque blue - 17.88
Yellow - 16.65	White = 18.08
Orange yellow - 16.67	
Gray = 16.87	
Dark Green - 16.90	

2b.3.4 SUMMARY/CONCLUSION

The problem of obtaining an estimate of evaporation from an area is a very difficult task in most instances and is often simplified by using representative point estimates in catchments (watersheds) or sub-catchments. The estimation of areal evapotranspiration is more difficult because of evaporating surfaces diversity in most watersheds, and the consequent need for a proportionally large number of ET measuring points, which are often expensive to install and maintain. The use of remote sensing techniques, combined with a limited number of appropriate ground measurements, could solve some of these areal estimation problems cost-effectively.

The remote sensing-aided system developed by RSRP to estimate evapotranspiration is designed to give timely, relatively accurate, cost effective evapotranspiration estimates on a watershed or sub-watershed basis. The system employs a basic two stage, two phase sample of three information resolution levels to estimate this important water yield-water use related quantity.

A necessary documentation of assumptions, structure, and limitations of current evapotranspiration models has been performed. Based on this analysis recommendations have been made concerning the applicability of these models to evapotranspiration estimation at various information levels corresponding to given stages and phases of the sampling design. Factors affecting evapotranspiration have been identified. Current data sources and available data types necessary to support evapotranspiration estimation are listed.

Based on the foregoing design, documentation, and feasibility analysis, work is now proceeding to implement the remote sensing-aided system. Effort will be focused on refining the sample design, developing in detail the supporting data flow mechanism, gathering additional data, and modifying the evapotranspiration models for their respective information levels. These modifications will be based on the performance of the proposed ET models at their information resolution level. Model performance will be evaluated relative to observed evaporation data and point-estimations of actual evapotranspiration data. These point estimations of actual ET data are based on energy-balance (with or without Bowen ratio) utilizing the measured values of the input variables on the ground. The energy balance method has repeatedly been shown to be a reliable and conservative method of determining evapotranspiration for periods of time as short as one hour.

Net radiation is the key quantity in the energy-balance equation, and the degree of accuracy obtainable by the method depends mainly on the accuracy with which this can be measured. Although national networks for

the measurement of total radiation have expanded steadily in recent years, the measurement of net radiation has not followed at the same rate. Two good reasons for this are the fragility of the equipment and the difficulty of determining a representative surface.

The input data for models requiring spatial information will be provided by a computer-aided databank. The RSRP software for this databank, known as MAPIT, will allow a geometrically coincident combination of LANDSAT-related data, environmental satellite data, ground meteorological station data, ground sample unit information gathered by RSRP and others, and topographic data.

Input data sets and evapotranspiration estimate output will be coordinated with concurrent sensitivity analyses of State of California water yield models performed jointly by the Davis and Berkeley NASA Grant groups. Initial data set location will be specific to the Spanish Creek Watershed, a representative subarea of the Feather River Watershed. Later expansion to the entire Feather River Watershed, the NASA Grant water supply test site, will occur after the economical testing on the smaller basin is completed.

The final product will be a documentation of any improvements in accuracy, timeliness, and cost considerations for the determination of water yield attributable to the remote sensing-aided evapotranspiration estimation system. Results will be specific to the state-of-the-art hydrologic models under examination.

2b.3.5 FUTURE RESEARCH

The evapotranspiration future research are as follows:

1. Continuation of Climatic Data Collection for the various information levels.

2. Comparison of performance of level I models and selection of the most fitted model to the watershed.

3. Application of level II models and selection of a representative model for level II.

4. Development and application of level III models.

5. Collection of Profile Climatic Data for the estimation of actual site-specific forest evapotranspiration to be used as a base for modification of ET models.

6. Application of radiation models and its comparison with the measured values.

7. Application of ET model results as an input to the operational hydrological models and performance of a sensitivity analysis for effect of ET on the water yield estimation.

2b.4 IMPERVIOUS SURFACE AREA ESTIMATION

2b.4.1 INTRODUCTION

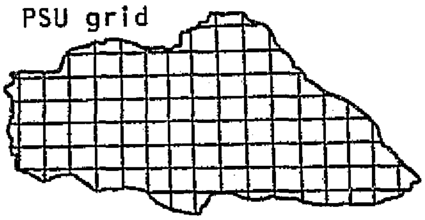
The water impervious surface area (ISA) is an important parameter in estimating water runoff. ISA's may be described as those areas which exhibit almost instantaneous runoff into adjacent areas and stream channels when precipitation occurs. Areas of this nature include lakes, bogs, swamps, bare rock surfaces and outcroppings, compacted soil, and paved areas (urban regions). Each of these areas may be classified as "hard" or permanently impervious surfaces. Meadow areas are areas which become impervious surfaces upon saturation; these temporarily impervious surfaces will be referred to simply as meadow ISA's. Stream channels and areas of riparian vegetation are areas impervious to precipitation most of the time (Kirkby, 1971). These areas, another type of temporarily impervious surface, may be classified as "soft" ISA's.

For the most part, these hard, meadow, and soft ISA's represent a small portion of any watershed. The dominant portion of any basin consists of those areas which may be called pervious surface areas (PSA's), into which precipitation usually infiltrates and begins a slow process of throughflow and sub-surface infiltration. An important aspect of these PSA's is that, upon saturation either from a very long period of precipitation or from the rate of precipitation being greater than the rate of infiltration, these areas exhibit a phenomenon known as saturation overflow which will rapidly increase the amount of water entering the drainage system during a precipitation input. For this reason, knowledge of areas of different types and rates of throughflow is very important in making water runoff predictions. The procedures which we are about to describe have been designed to be applicable to both ISA and PSA estimations, but this study shall address primarily the former.

2b.4.2 MATERIALS AND METHODS

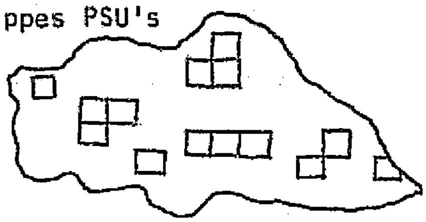
The method employed in this study has been designed to accurately and cost-effectively estimate the hard, meadow and soft ISA's in such a manner so to be statistically applicable in water-yield estimation models. A multi-stage sampling approach is a fast , step-by-step method of analysis at ever increasing levels of accuracy, in which each step may be used to calibrate the data from the previous step (see figure 2b.12). For convenience and practicality, a method of measuring ISA's by unit area within grid units was preferred over a point-by-point identification method. This method of unit area measurement fits well into the multi-stage sampling approach as ever smaller sub-units may be used in sub-stage samples. In addition, a unit area measurement can be more easily applied to water-yield estimation models.

Figure 2b.12 ISA Multi-stage Sampling Method

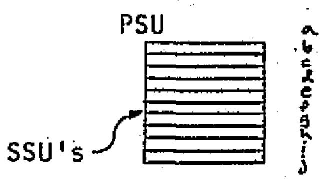


LANDSAT imagery at 1:100,000 scale

1. Geologic-Geomorphic stratification.
2. Identification (Geologic map).
3. 2 km. grid application.
4. ISA classification estimates for all PSU's.
5. Select units for secondary classification with proportional to estimated size (ppes) of PSU ISA area.

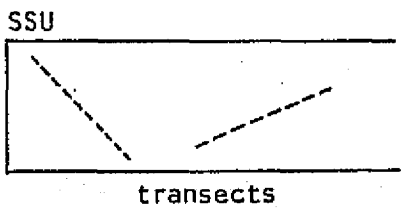


Infared
Highflight imagery at 1:120,000 scale



6. Transfer of PSU to highflight imagery.
7. Location of SSU units.
8. Second level classification estimated for all SSU's.
9. Select units for tertiary classification with ppes of SSU ISA area, if needed.

Lowflight imagery or ground survey



10. Transfer of SSU to lowflight imagery.
11. Location of transects (TSU's) over areas of interest.
12. Tertiary classification estimates for all TSU's.

13. Summarize data, develop correction values for PSU estimates.

Initial stratification of the watershed is accomplished by means of a delineation of geologic and geomorphic areas. This is done on multiband color composite LANDSAT imagery at a scale of 1:100,000 for reasons of equal lighting intensity[1], ease of sample grid location, availability of LANDSAT data over a large area and to a great number of possible investigators, and the potential application of information to automatic analysis. The geologic stratification yields estimations for hard and meadow areas, but the bulk of the information remains to be used for PSA analysis.[2] The geomorphic stratification involves the delineation of the drainage network, and division of the watershed into areas of different types of drainage patterns and different overall aspect.[3] For ISA analysis delineation of the drainage network is the most important part of the first step, as it affects directly the estimation of potential areas of riparian vegetation (soft ISA's). In studies of larger areas, these stratifications may also be used in stratified-random selection of primary sample units to be sub-sampled on highflight imagery as the second step of the multi-stage sampling approach.

Following geologic and geomorphic stratification, the next step is to superimpose a primary sample unit (PSU) grid covering the watershed. For each square (or rectangular) PSU, an estimate is made of the percent surface area falling in hard, meadow, and soft ISA categories, respectively. At this point summation of each class is possible and the first level estimation of the total ISA in each category may be obtained.

Second-stage sampling begins with probability-proportional-to-estimated-size (ppes) of the ISA area random sampling (or stratified ppes sampling for large areas) of PSU's for analysis on highflight imagery. Once the number of units needed to achieve a designated allowable error has been determined, sub-sample unit selection is made from a cumulative summation of the ISA measurements. Within each selected PSU, horizontal SSU's are laid across the PSU from top to bottom on highflight imagery, and SSU estimations of each ISA class are made. Data from SSU's are used to calibrate the PSU estimations. Third stage sampling may be done for additional refinement of data. This sampling may be done on lowflight imagery (1:1000-1:3000 scale), or by ground survey, by allocating transacts (TSU's) taken within certain ppes selected SSU's.

Multi-date change detection is used to analyze seasonal variations in parameters of interest over the study area. The multi-date composite consists of an image composed of one LANDSAT band only, for two different dates. Each date is exposed as a different contrasting color (red and cyan).

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[1]Not possible with highflight imagery due to vignetting problem.

[2]Should the primary goal of a study be only the delineation of ISA's, the geologic stratification may be done only to the extent of identifying hard and meadow ISA's.

[3]As with geologic stratification the bulk of this work is applicable to the PSA study.

The resultant image is one on which areas of no change are a neutral color grey, while areas which have changed on one band or the other are either red or cyan, respectively. This process uses either both positive or both negative originals, and therefore retains original shadows and contrasts permitting easy relief identification.

2b.4.2.1 Geologic-Geomorphic Stratification Inputs

As part of the geologic stratification, color combinations of different bands of LANDSAT imagery were examined to determine the best combination for stratification of the Spanish Creek study area. Using the same change detection techniques described earlier to study differences between the bands, it was determined that a color composite of bands 5, 6, and 7 would provide the information needed for stratification. The color assignments chosen for the bands were: band 5-green; band 6-blue; and band 7-red. This color combination produces a final print in yellow tones, which the interpreter may find easier to distinguish than orange tones which result with standard color assignments for these bands.

For geologic-geomorphic stratification, color composites of each wet, interim, and dry season have major differences in the amount of recognizable detail, as partially described by Rootenboer (1973). Streams are easy to identify on the wet season color composite because of flooding, while on the interim and dry season composites highly reflective dry bands are exposed. Vegetation changes over the seasons enable better delineation of different types of vegetation, and variations in soil moisture change, the amount of reflection, permitting better identification of different soil types.

2b.4.2.2 Procedures for Geologic-Geomorphic Stratification

It is important to choose cloud-free LANDSAT imagery for use in multi-band (5, 6, 7) color composites[4] of each wet, interim, and dry seasons, and to have prints produced at a scale sufficiently large for annotation (1:100,000). On an acetate overlay to one of the season color composites, delineate the boundary of the drainage basin and the drainage network. Depending on terrain conditions, it may be necessary to use each of the season composites to delineate the full network. Stratification of the watershed into areas of different drainage patterns (i.e., dendritic, parallel, radial, trellas, etc.) and by overall, or average, aspect is necessary to the PSA study and may be useful for stratification of large areas in later subsampling.

For estimations of ISA's, the delineation and identification of urban, lake, bare rock surfaces and outcroppings, and meadow areas is necessary. For estimations to be used in the PSA study, full delineation and identification of all geologic areas is needed. On acetate covering the LANDSAT composite delineate all vegetation, soil, and rock areas of similar type, density, texture, and color (Goetz, et. al. 1973). Comparison of wet, interim, and dry season composites will often yield more definitive area boundaries, but care must be taken to avoid the problems due to variation of sun-angle on the respective images. These delineations are, in general agreement with the basic geologic boundaries of the area as

[4] Band 5-green; 6-blue; 7-red.

represented on a 1:250,000 scale geologic map[5] (see figure 2b.13). The accuracy of the LANDSAT image geologic delineations will not be as detailed as those compiled by ground survey, but will be better than those done by reconnaissance. Geologic maps may be used for identifying areas of delineation, pending availability of such maps. For areas that have not been mapped, ground truth data collection is a necessary sub-stage of the study.

Basic geologic types within the Spanish Creek watershed are shown in Table 2b.8.

<u>TABLE 2b.8</u>

Mississippian Marine (Cm, listed as m)
Permian Marine (Pm, listed as m)
Paleozoic Marine (IP, listed as m)[6]
Triassic Marine (Ŧ, listed as m)

Paleozoic Metavolcanics (IPv, listed as mv)[6]
Pre-Cretaceous Metavolcanics (mv, listed as mv)
Jura-Triassic Metavolcanics (JŦv, listed as mv)

Mesozoic ultrabasic intrusives (serpentine)(ub)[6]
Mesozoic granitic (bare rock surfaces and outcrops)(gr), hard ISA

Tertiary volcanics - andesite (Tv^a, listed as v^a)
- basalt (Tv^b, listed as v^b)
Eocene volcanics - basalt (Ev^b, listed as v^b)

Pliocene volcanics - basalt (Ev^b, listed as v^b)[6]
- pyroclastic (PvP, listed as v^p)[6]
Pleistocene volcanics - basalt (Qpv^b, listed as v^b)

Eocene non-marine (Ec)
Quaternary glacial deposits (Qg)
Quaternary lake deposits (Ql)[6], meadow ISA
Alluvium (Qal)[6], meadow ISA

Lakes, hard ISA
Urban areas, hard ISA

Areas of marine sediments, metavolcanics, serpentine, granite, volcanics, and quaternary deposits are each easily distinguished on the LANDSAT imagery. In areas of marine sediment, some of the age sub-classes can be distinguished; in Quaternary deposits differentiation between types

[5]State of California, Division of Mines and Geology, Geologic Map of California: Chico Sheet (1962) and Westwood Sheet (1960)

[6]Dominant geologic types.

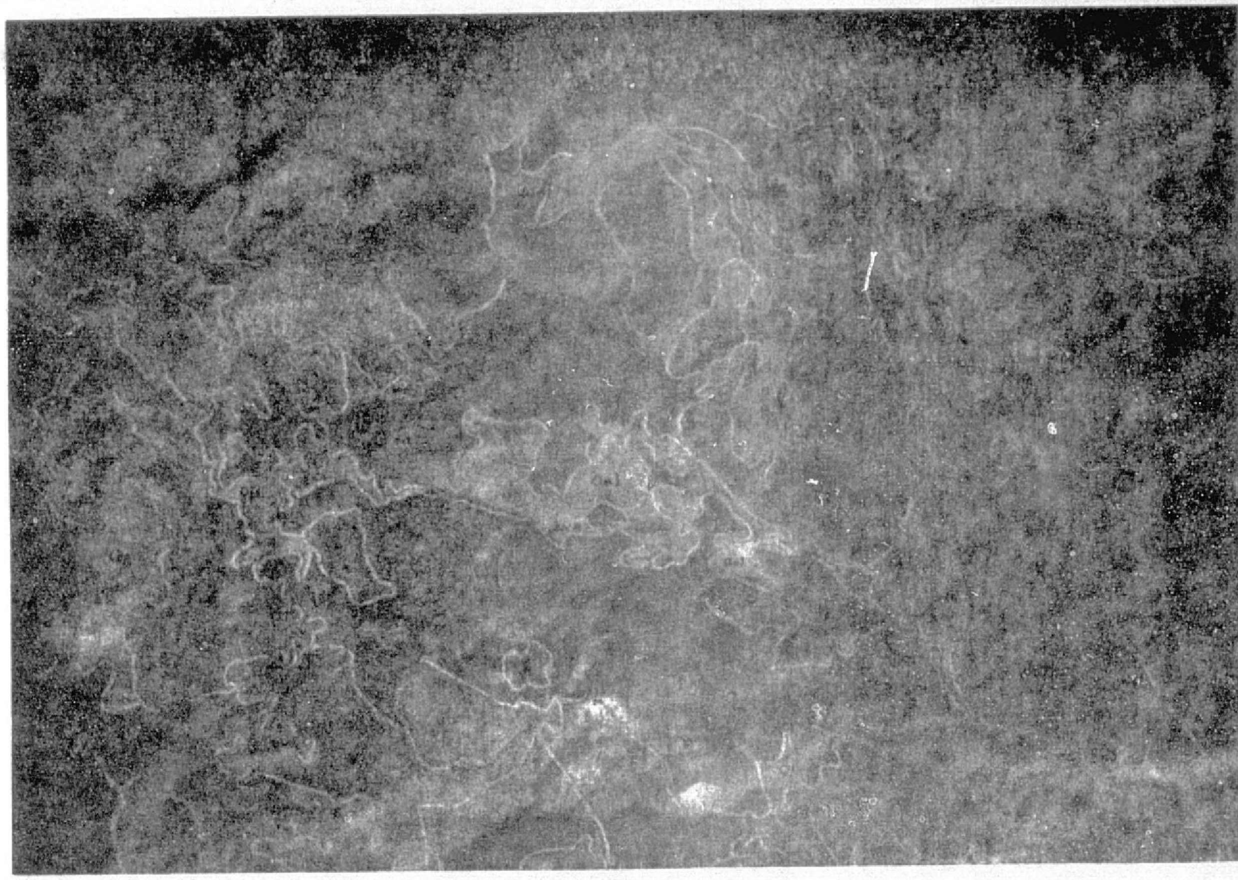


Figure 2b.13 Geologic deliniation of the Spanish Creek watershed as listed in Table shown over the 13 Sept 1973 LANDSAT multi-band (5,6,7) color composite. Identifications are as follows:

m - marine sediments
mv - metavolcanics
v - volcanics (b -basaltic)
(p -pyroclastic)
gr - granite
ub - serpentine
E - Eocene deposits
Qg - glacial deposits
Ql - Quarternary lake deposits
Qal - Alluvium

of deposits is apparent (Qg, Ql, Qal). Sub-classes in areas of metavolcanics and volcanics are less easily discerned. Lakes and urban areas could be easily identified on all the images. For the purposes of this study identifications were limited to geologic types even though many areas could be delineated by specific age sub-classes. Age classifications may be done at a later time for use in a PSA study

2b.4.2.3 Sample Unit Grid Design

The sample unit grid design for the ISA estimation is based on KATIBAH (1975) using a grid to divide the study area into well defined uniform units which allow the image analyst to make discrete decisions about the extent of ISA within each unit. This technique produces ISA area-measurements applicable to direct summation to estimate total ISA over the entire watershed, and is applicable to other water outflow prediction models.

The sample unit grid cell size for the Spanish Creek watershed was 2km on a side. The total number of sample units over the entire watershed was 134 (106 full units, and 54 partial units). By this measure the area of the watershed is 536 km^2 ($134 x 4km^2$). For sample unit identification a coordinate system was chosen using numbers 1-21 on the x-Axis, and letters A-M on the y-Axis. This method was chosen over numbering the individual units, because it permits easy identification of adjacent units (see figure 2b.14).

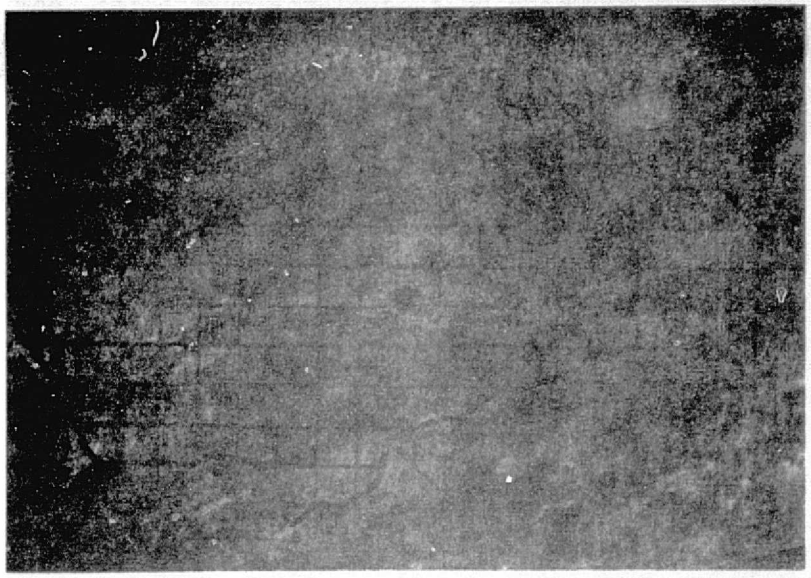
2b.4.2.4 Procedures for Hard (g), Meadow(m) and Soft(X_s) ISA Estimation

In using a 2 km grid on a 1:100,000 scale image, each sample unit is 2 cm on a side. For interpretation at this scale it was arbitrarily decided to use a minimum unit area of 0.1 $(2km)^2$ or 40 hectares; this is a grid area of 0.1 $(2cm)^2$ on the imagery or a tenth of a sample unit.

For sample unit area estimation of outcroppings, lakes, urban areas (g) and meadows (m) each of which is part of the geologic stratification, this minimum unit area may be used as a direct measure. But for stream channels and areas of riparian vegetation direct area approximation using this minimum sample unit is very difficult for two reasons: 1) being long, narrow areas along the drainage network, the shape and size of the areas make them visually difficult to accurately approximate the area of relative to sample unit size, and 2) the extent of the actual area of riparian vegetation is difficult or impossible to see on LANDSAT imagery, even though the drainage network is readily identifiable. For these reasons the following methodology for soft ISA estimation has been developed.

Areas (X_s) within 400 meters (.4 cm on 1:100,000 imagery) of either side of stream channels should be delineated over the extent of the drainage network. Area estimation of this class (X_s) on the 2 km (2 cm) sample grid is relatively simple; however, due to the use of the 400 meter criterion, measures yielded from this estimation must be corrected by a relative value of $1/\alpha$ to reflect an actual area value for soft ISA. For the initial sampling level using LANDSAT 1:100,000 imagery a value of

Figure 2b.14



Boundary of the Spanish Creek watershed with the 2 km. PSU sample grid, shown over the 26 July 1972 LANDSAT multi-band (5,6,7) color composite.

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$\alpha_1 = 8$ has been arbitrarily assumed, yielding an actual measure of area 50 meters on either side of the stream channels. One purpose of second stage sampling will be be to determine a more precise value for α.

Actual listing of measured surface areas (g, m, Xs) must include: unit coordinates, unit size, geologic stratifications by sample unit (the sum of which must equal the unit size), and the area of X_s, each to the nearest tenth of a sample unit. From these data all other computations for ISA and later studies may be computed.

Estimation of ISA may now be made by taking the summation of each hard (g), meadow, less soft ISA areas ($m-X_s/\alpha$), and soft ISA's multiplying each by the unit area $(2km)^2$, as shown in the formula (X_s/α),

$$g(2km)2 \quad + \quad p_s(m - X_s/\alpha)\ (2km)^2 \quad + \quad X_s/\alpha\ (2km0^2 = \text{total ISA}$$

HARD ISA	MEADOW ISA	SOFT ISA
Lakes bogs swamps urban areas fare road & outcrops	meadow areas less inherent riparian vegetation areas & stream channels	riparian vegetation areas and stream channels

Since moisture content of meadows fluxuates over the year, and therefore imperability, a moisture factor (ps) has been included.

In the Sacramento River Forecasting Center (RFC) model, ISA so defined here consists of a permanently water impervious surface area component, g $(2km)^2$, and two temporarily impervious surface area components, $ps(m-X_s/\alpha)(2km)^2$ and $X_s/\alpha\ (2km)^2$, which readily become impervious upon water input.

2b.4.2.5 Sub-sampling Procedures

Soft ISA (X_s) data were used for selection of sub-sampling PSU units because:

1. The primary purpose of sub-sampling is the refinement of α (on X_s correction factor).
2. X_s is a direct factor of the drainage system, and this is a hydrology-related study.
3. The number of units with an X_s value is greater than the number with a value for either g or m.

4. g and m can be obtained relatively accurately from LANDSAT data, while this is not always true of X_s.

The first step in sub-sample unit selection is making a cumulative-sum list of all X_s/α_1 (see Table 2b.9). In addition, another summation of all $(X_s/\alpha_1)^2$ is needed in order to calculate the variance (v(y)) and the coefficient of variation (CV).

$$v(y) = \frac{\sum\left(\frac{X_s}{\alpha_1}\right)^2 - \frac{\left(\sum\frac{X_s}{\alpha_1}\right)^2}{N}}{N-1} \qquad (1)$$

$$CV = \frac{\sqrt{v(y)}}{\bar{Y}} \times 100 \qquad (2)$$

where N is the total number of non-zero X_s sample units and $\bar{Y}$ is the average of X_s/α_1. Knowing these figures, the number of sample units needed to achieve a user-selected level of allowable error (AE) can be found via formula 3:

$$n = \frac{N\ t^2\ CV^2}{N(AE)^2 + t^2 CV^2} \qquad (3)$$

where t represents the Student-t statistic, and n is the number of first stage sample units (PSU's) to be selected for subsampling. For the first calculation of n, a tabulated t value at $n=\infty$ (i.e. infinite degrees of freedom, N-1) must be used to find an approximate value for n from which a new t value can be assigned, and which will yield a more exact value for n.

With n determined, n number of random numbers must be drawn from a random number table, each of which is within the range of zero to $\sum X_s/\alpha_1$. These random numbers are then used to draw, from the cumulative list, the PSU's for subsampling (e.g. 2.0351 is a drawn random number. It is between 2.0250 and 2.0875 of the cumulative list in Table 2b.9 (thus unit 9B is selected). Note that PSU's are selected with probability proportional to size of X_s/α_1. In the case of duplicate selection, the unit will be used both times, and yield two SSU (secondary sample units) instead of one when SSU's are selected for tertiary sampling (transects, see below).

Table 2b.9 Geologic/Geometric Characteristics of Spanish Creek Watershed Based on LANDSAT data.

		GEOLOGIC					GEOMORPHIC							
UNIT	SIZE	PSA	g	m	$m \cdot X_5/\alpha_1$	$m \cdot X_5/\alpha$	AREA	X_5	X_5/α_1	cum X_5/α_1	X_1	X_2	X_5/α	cum X_5/α
1G	.3	M	0.0	0.0	0.00000	0.00000	7	0.0	0.00000	0.00000	0.0	0.0	0.00000	0.00000
1H	.4	.2QG .1M	.1LAK	0.0	0.00000	0.00000	7	.2	.02500	.02500	0.0	.2	.01250	.01250
1I	.1		.1GR	0.0	0.00000	0.00000	7	.1	.01250	.03750	0.0	.1	.00625	.01875
2F	.1	UB	0.0	0.0	0.00000	0.00000	7	0.0	0.00000	.03750	0.0	0.0	0.00000	.01875
2G	.9	.6M .2M .1UB	0.0	0.0	0.00000	0.00000	7	.3	.03750	.07500	0.0	.3	.01875	.03750
2H	1.0	.8QG .1M	.1LAK	0.0	0.00000	0.00000	7	.6	.07500	.15000	0.0	.6	.03750	.07500
2I	.8		.8GR	0.0	0.00000	0.00000	7	.4	.05000	.20000	0.0	.4	.02500	.10000
3G	1.0	.4M .3M .2UB .1VP	0.0	0.0	0.00000	0.00000	7	.3	.03750	.23750	0.0	.3	.01875	.11875
3H	1.0	.8M .2QG	0.0	0.0	0.00000	0.00000	7	.3	.03750	.27500	0.0	.3	.01875	.13750
3I	1.0	.7QG .3M	0.0	0.0	0.00000	0.00000	7	.4	.05000	.32500	0.0	.4	.02500	.16250
3J	.9	QG	0.0	0.0	0.00000	0.00000	7	0.0	0.00000	.32500	0.0	0.0	0.00000	.16250
3K	.7	.4QG .3M	0.0	0.0	0.00000	0.00000	6	.2	.02500	.35000	0.0	.2	.01250	.17500
3L	.3	QG	0.0	0.0	0.00000	0.00000	6	.2	.02500	.37500	0.0	.2	.01250	.18750
3M	.1		.1GR	0.0	0.00000	0.00000	6	0.0	0.00000	.37500	0.0	0.0	0.00000	.18750
4F	.4	VP	0.0	0.0	0.00000	0.00000	7	0.0	0.00000	.37500	0.0	0.0	0.00000	.18750
4G	1.0	.5VP .3UB .2EC	0.0	0.0	0.00000	0.00000	7	.1	.01250	.38750	0.0	.1	.00625	.19375
4H	1.0	.4M .3UB .1VP	0.0	.2QL	.12500	.15625	7	.6	.07500	.46250	.1	.5	.04375	.23750
4I	1.0	M	0.0	0.0	0.00000	0.00000	7	.4	.05000	.51250	0.0	.4	.02500	.26250
4J	1.0	.9M .1QG	0.0	0.0	0.00000	0.00000	6	.7	.08750	.60000	.3	.4	.06250	.32500
4K	1.0	M	0.0	0.0	0.00000	0.00000	6	.4	.05000	.65000	0.0	.4	.02500	.35000
4L	1.0	.5M .1QG	.4GR	0.0	0.00000	0.00000	6	.5	.06250	.71250	0.0	.5	.03125	.38125
4M	.3		.3GR	0.0	0.00000	0.00000	6	0.0	0.00000	.71250	0.0	0.0	0.00000	.38125
5F	.7	VP	0.0	0.0	0.00000	0.00000	4B	0.0	0.00000	.71250	0.0	0.0	0.00000	.38125
5G	1.0	.7VP .3M	0.0	0.0	0.00000	0.00000	4B	.4	.05000	.76250	0.0	.4	.02500	.40625
5H	1.0	.3UB .2M	0.0	.5QL	.41250	.41250	7	.7	.08750	.85000	.7	0.0	.08750	.49375
5I	1.0	.4M	0.0	.6QL	.52500	.53125	6	.6	.07500	.92500	.5	.1	.06875	.56250
5J	1.0	M	0.0	0.0	0.00000	0.00000	6	.5	.06250	.98750	0.0	.5	.03125	.59375
5K	1.0	.7M .3VP	0.0	0.0	0.00000	0.00000	6	.4	.05000	1.03750	0.0	.4	.02500	.61875
5L	.5	.2M	.3GR	0.0	0.00000	0.00000	6	0.0	0.00000	1.03750	0.0	0.0	0.00000	.61875
6E	-	M	0.0	0.0	0.00000	0.00000	4B	.2	.02500	1.06250	0.0	.2	.01250	.63125
6F	1.0	.8M .2VP	0.0	0.0	0.00000	0.00000	4B	.8	.10000	1.16250	0.0	.8	.05000	.68125
6G	1.0	.7M .3VP	0.0	.2QL	.12500	.15625	4B	.6	.07500	1.23750	.1	.5	.04375	.72500
6H	1.0	.5M .3UB	0.0	.2QL	.13750	.13750	5	.5	.06250	1.30000	.5	0.0	.06250	.78750
6I	1.0	.6UB .4M	0.0	.2QL	.11250	.13125	6	.7	.08750	1.38750	.4	.3	.06875	.85625
6J	1.0	.5M .5M	0.0	0.0	0.00000	0.00000	6	.2	.02500	1.41250	0.0	.2	.01250	.86875
6K	.9	.6VP .3M	0.0	0.0	0.00000	0.00000	6	0.0	0.00000	1.41250	0.0	0.0	0.00000	.86875
7B	.1	M	0.0	0.0	0.00000	0.00000	1	.1	.01250	1.42500	.1	0.0	.01250	.88125
7C	.2	M	0.0	0.0	0.00000	0.00000	4A	.1	.01250	1.43750	.1	0.0	.01250	.89375
7D	.1	M	0.0	0.0	0.00000	0.00000	4B	0.0	0.00000	1.43750	0.0	0.0	0.00000	.89375
7E	.8	.6M .2M	0.0	0.0	0.00000	0.00000	4B	.1	.01250	1.45000	0.0	.1	.00625	.90000
7F	1.0	.6M .2M	.2LAK	0.0	0.00000	0.00000	4B	.6	.07500	1.52500	.6	0.0	.07500	.97500
7G	1.0	.9M	0.0	.1QL	.03750	.06875	4B	.5	.06250	1.58750	0.0	.5	.03125	1.00625
7H	1.0	.7M .1UB	0.0	.2QL	.12500	.12500	5	.6	.07500	1.66250	.6	0.0	.07500	1.08125
7I	1.0	.5UB .4M	0.0	0.0	0.00000	0.00000	5	.7	.08750	1.75000	0.0	.7	.04375	1.12500
7J	1.0	.6M .1UB .1VP	0.0	0.0	0.00000	0.00000	5	.6	.07500	1.82500	0.0	.6	.03750	1.16250
7K	1.0	.7VP .3M	0.0	0.0	0.00000	0.00000	5	.4	.05000	1.87500	0.0	.4	.02500	1.18750
7L	.3	VP	0.0	0.0	0.00000	0.00000	5	0.0	0.00000	1.87500	0.0	0.0	0.00000	1.18750
8B	.7	.4MV .3M	0.0	0.0	0.00000	0.00000	1	.4	.05000	1.92500	.4	0.0	.05	1.23750
8C	1.0	.9M .1M	0.0	0.0	0.00000	0.00000	4A	.6	.07500	2.00000	.6	0.0	.07500	1.31250
8D	.8	.7M	0.0	.1QAL	.03750	.03750	4A	.5	.06250	2.06250	.5	0.0	.06250	1.37500
8E	1.0	M	0.0	0.0	0.00000	0.00000	4A	.4	.05000	2.11250	0.0	.4	.02500	1.40000
8F	1.0	M	0.0	0.0	0.00000	0.00000	4A	0.0	0.00000	2.11250	0.0	0.0	0.00000	1.40000
8G	1.0	.7M	0.0	.3QAL	.23750	.23750	4B	.5	.06250	2.17500	.5	0.0	.06250	1.46250
8H	1.0	M	0.0	0.0	0.00000	0.00000	3	.1	.01250	2.18750	0.0	.1	.00625	1.46875
8I	1.0	M	0.0	0.0	0.00000	0.00000	3	.2	.02500	2.21250	0.0	.2	.01250	1.48125
8J	1.0	.4M .2UB	0.0	0.0	0.00000	0.00000	5	.5	.06250	2.27500	0.0	.5	.03125	1.51250
8K	1.0	.4M .4UB .2VP	0.0	0.0	0.00000	0.00000	5	.4	.05000	2.32500	0.0	.4	.02500	1.53750
8L	.9	VP	0.0	0.0	0.00000	0.00000	5	.3	.03750	2.36250	0.0	.3	.01875	1.55625
8M	.4	.3VP .1EC	0.0	0.0	0.00000	0.00000	5	0.0	0.00000	2.36250	0.0	0.0	0.00000	1.55625
9A	.3	.2MV .1MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	2.36250	0.0	0.0	0.00000	1.55625

Table 2b.9 (continued)

		GEOLOGIC					GEOMORPHIC							
UNIT	SIZE	PSA	θ	m	$m - X_s/\alpha_1$	$m - X_s/\alpha$	AREA	X_s	X_s/α_1	cum X_s/α_1	X_1	X_7	X_s/α	cum X_s/α
9B	1.0	.4MV .3MV .3M	0.0	0.0	0.00000	0.00000	1	.5	.06250	2.42500	0.0	.5	.03125	1.56750
9C	1.0	M	0.0	0.0	0.00000	0.00000	1	.6	.07500	2.50000	.1	.5	.04375	1.63125
9D	1.0	M	0.0	0.0	0.00000	0.00000	4A	.9	.11250	2.61250	.5	.4	.08750	1.71875
9E	1.0	M	0.0	0.0	0.00000	0.00000	4A	.2	.02500	2.63750	0.0	.2	.01250	1.73125
9F	1.0	M	0.0	0.0	0.00000	0.00000	4A	0.0	0.00000	2.63750	0.0	0.0	0.00000	1.73125
9G	1.0	.4M	0.0	.60AL	.50000	.50000	4B	.8	.10000	2.73750	.8	0.0	.10000	1.83125
9H	1.0	M	0.0	0.0	0.00000	0.00000	3	0.0	0.00000	2.73750	0.0	0.0	0.00000	1.83125
9I	1.0	M	0.0	0.0	0.00000	0.00000	3	0.0	0.00000	2.73750	0.0	0.0	0.00000	1.83125
9J	1.0	.9M .1UB	0.0	0.0	0.00000	0.00000	5	.7	.08750	2.82500	0.0	.7	.04375	1.87500
9K	1.0	UB	0.0	0.0	0.00000	0.00000	5	0.0	0.00000	2.82500	0.0	0.0	0.00000	1.87500
9L	.9	.5VP .4UB	0.0	0.0	0.00000	0.00000	5	0.0	0.00000	2.82500	0.0	0.0	0.00000	1.87500
10A	.8	.4MV .4MV	0.0	0.0	0.00000	0.00000	1	.6	.07500	2.90000	0.0	.6	.03750	1.91250
10B	1.0	MV	0.0	0.0	0.00000	0.00000	1	.1	.01250	2.91250	0.0	.1	.00625	1.91875
10C	1.0	.6MV .4M	0.0	0.0	0.00000	0.00000	1	.5	.06250	2.97500	0.0	.5	.03125	1.95000
10D	1.0	.8M .2MV	0.0	0.0	0.00000	0.00000	1	.7	.08750	3.06250	.6	.1	.08125	2.03125
10E	1.0	.9M	0.0	.10AL	.05000	.07500	4A	.4	.05000	3.11250	0.0	.4	.02500	2.05625
10F	1.0	.8M	0.0	.20AL	.11250	.14375	4A	.7	.08750	3.20000	.2	.5	.05625	2.11250
10G	1.0	.2M	.2URB	.60AL	.50000	.50000	3	.8	.10000	3.30000	.8	0.0	.10000	2.21250
10H	1.0	.8M	.2URB	0.0	0.00000	0.00000	3	.5	.06250	3.36250	0.0	.5	.03125	2.24375
10I	1.0	M	0.0	0.0	0.00000	0.00000	3	.5	.06250	3.42500	0.0	.5	.03125	2.27500
10J	1.0	.6VB .4M	0.0	0.0	0.00000	0.00000	5	.3	.03750	3.46250	0.0	.3	.01875	2.29375
10K	.6	.5VB .3VP	0.0	0.0	0.00000	0.00000	5	0.0	0.00000	3.46250	0.0	0.0	0.00000	2.29375
10L	.4	VP	0.0	0.0	0.00000	0.00000	5	0.0	0.00000	3.46250	0.0	0.0	0.00000	2.29375
11A	.6	.5MV .1OG	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	3.46250	0.0	0.0	0.00000	2.29375
11B	1.0	.6MV .3MV .1OG	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	3.46250	0.0	0.0	0.00000	2.29375
11C	1.0	.5MV .5MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	3.46250	0.0	0.0	0.00000	2.29375
11D	1.0	.5M .4MV	0.0	0.0	0.00000	0.00000	1	.4	.05000	3.51250	.2	.2	.03750	2.33125
11E	1.0	.9M	0.0	.10AL	.00000	.00625	4A	.8	.10000	3.61250	.7	.1	.09375	2.42500
11F	1.0	.3M	0.0	.70AL	.63750	.63750	4A	.5	.06250	3.67500	.5	0.0	.06250	2.48750
11G	1.0	.3M	.4URB	.30AL	.22500	.22500	3	.6	.07500	3.75000	.6	0.0	.07500	2.56250
11H	1.0	.9M	0.0	.10AL	.06250	.07500	3	.3	.03750	3.78750	.1	.2	.02500	2.58750
11I	1.0	M	0.0	0.0	0.00000	0.00000	3	.6	.07500	3.86250	0.0	.6	.03750	2.62500
11J	.9	.7M .1MV .1VP	0.0	0.0	0.00000	0.00000	3	.2	.02500	3.88750	0.0	.2	.01250	2.63750
11K	.1	VP	0.0	0.0	0.00000	0.00000	5	0.0	0.00000	3.88750	0.0	0.0	0.00000	2.63750
12A	.5	.4MV .1M	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	3.88750	0.0	0.0	0.00000	2.63750
12B	1.0	.7MV .3M	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	3.88750	0.0	0.0	0.00000	2.63750
12C	1.0	MV	0.0	0.0	0.00000	0.00000	1	.1	.01250	3.90000	0.0	.1	.00625	2.64375
12D	1.0	.9MV .1M	0.0	0.0	0.00000	0.00000	1	.7	.08750	3.98750	0.0	.7	.04375	2.68750
12E	1.0	.6M .4MV	0.0	0.0	0.00000	0.00000	1	.3	.03750	4.02500	0.0	.3	.01875	2.70625
12F	1.0	.4M .2M	0.0	.40AL	.30000	.31875	1	.8	.10000	4.12500	.5	.3	.08125	2.78750
12G	1.0	.3M	.4URB	.30AL	.25000	.27500	3	.4	.05000	4.17500	0.0	.4	.02500	2.81250
12H	1.0	.3M	.1URB	0.0	0.00000	0.00000	3	.5	.06250	4.23750	0.0	.5	.03125	2.84375
12I	1.0	M	0.0	0.0	0.00000	0.00000	3	0.0	0.00000	4.23750	0.0	0.0	0.00000	2.84375
12J	.8	M	0.0	0.0	0.00000	0.00000	3	0.0	0.00000	4.23750	0.0	0.0	0.00000	2.84375
13A	.3	M	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	4.23750	0.0	0.0	0.00000	2.84375
13B	1.0	.6M .4MV	0.0	0.0	0.00000	0.00000	1	.1	.01250	4.25000	0.0	.1	.00625	2.85000
13C	1.0	.8MV .2M	0.0	0.0	0.00000	0.00000	1	.7	.08750	4.33750	0.0	.7	.04375	2.89375
13D	1.0	.5MV .5M	0.0	0.0	0.00000	0.00000	1	.7	.08750	4.42500	0.0	.7	.04375	2.93750
13E	1.0	.9MV	0.0	.10AL	.03750	.03750	1	.5	.06250	4.48750	.5	0.0	.06250	3.00000
13F	1.0	.5M .2MV .1M	0.0	.10AL	-.01250	.03125	1	.9	.11250	4.60000	.2	.7	.06875	3.06875
13G	1.0	.2M .2M	0.0	.60AL	.50000	.50000	2	.8	.10000	4.70000	.8	0.0	.10000	3.16875
13H	1.0	.7VP .3M	0.0	0.0	0.00000	0.00000	2	.2	.02500	4.72500	.2	0.0	.02500	3.19375
13I	1.0	M	0.0	0.0	0.00000	0.00000	2	.1	.01250	4.73750	0.0	.1	.00625	3.20000
13J	.1	M	0.0	0.0	0.00000	0.00000	3	0.0	0.00000	4.73750	0.0	0.0	0.00000	3.20000
14A	.1	M	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	4.73750	0.0	0.0	0.00000	3.20000
14B	.9	.5MV .4M	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	4.73750	0.0	0.0	0.00000	3.20000
14C	1.0	.8M .2MV	0.0	0.0	0.00000	0.00000	1	.4	.05000	4.78750	0.0	.4	.02500	3.22500
14D	1.0	M	0.0	0.0	0.00000	0.00000	1	.2	.02500	4.81250	0.0	.2	.01250	3.23750
14E	1.0	M	0.0	0.0	0.00000	0.00000	1	.5	.06250	4.87500	0.0	.5	.03125	3.26875
14F	1.0	.8M .2M	0.0	0.0	0.00000	0.00000	1	.2	.02500	4.90000	0.0	.2	.01250	3.28125

Table 2b.9 (continued)

GEOLOGIC							GEOMORPHIC							
UNIT	SIZE	PSA	Q	m	m-X_s/a_1	m-X_s/a	AREA	X_s	X_s/a_1	cum X_s/a_1	X_1	X_2	X_s/a	cum X_s/a
14G	1.0	.6M .3M	0.0	.1QAL	.01250	.01250	2	.7	.08750	4.98750	.7	0.0	.08750	3.36875
14H	1.0	.5M .4VB .1M	0.0	0.0	0.00000	0.00000	2	.7	.08750	5.07500	.4	.3	.06875	3.43750
14I	.9	.6M .2M .1VB	0.0	0.0	0.00000	0.00000	2	.5	.06250	5.13750	0.0	.5	.03125	3.46875
15B	.4	MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.13750	0.0	0.0	0.00000	3.46875
15C	1.0	MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.13750	0.0	0.0	0.00000	3.46875
15D	1.0	.9MV .5M	0.0	0.0	0.00000	0.00000	1	.1	.01250	5.15000	0.0	.1	.00625	3.47500
15E	1.0	.7MV .3M	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.15000	0.0	0.0	0.00000	3.47500
15F	1.0	M	0.0	0.0	0.00000	0.00000	1	.3	.03750	5.18750	0.0	.3	.01875	3.49375
15G	1.0	.4M .3M .2M .1MV	0.0	0.0	0.00000	0.00000	1	.7	.08750	5.27500	.3	.4	.06250	3.55625
15H	1.0	.8M .2VB	0.0	0.0	0.00000	0.00000	2	.4	.05000	5.32500	.2	.2	.03750	3.59375
15I	.5	.4VB .1M	0.0	0.0	0.00000	0.00000	2	0.0	0.00000	5.32500	0.0	0.0	0.00000	3.59375
16C	.7	.6MV .1MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.32500	0.0	0.0	0.00000	3.59375
16D	1.0	.9MV .1MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.32500	0.0	0.0	0.00000	3.59375
16E	1.0	MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.32500	0.0	0.0	0.00000	3.59375
16F	1.0	MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.32500	0.0	0.0	0.00000	3.59375
16G	1.0	.8MV .2M	0.0	0.0	0.00000	0.00000	1	.4	.05000	5.37500	0.0	.4	.02500	3.61875
16H	1.0	.8VB	0.0	.2QAL	.12500	.13125	2	.6	.07500	5.45000	.5	.1	.06875	3.68750
16I	.3	VB	0.0	0.0	0.00000	0.00000	2	0.0	0.00000	5.45000	0.0	0.0	0.00000	3.68750
17C	.2	MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.45000	0.0	0.0	0.00000	3.68750
17D	1.0	.9MV .1MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.45000	0.0	0.0	0.00000	3.68750
17E	1.0	.7MV .3MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.45000	0.0	0.0	0.00000	3.68750
17F	1.0	MV	0.0	0.0	0.00000	0.00000	1	.5	.06250	5.51250	0.0	.5	.03125	3.71875
17G	1.0	MV	0.0	0.0	0.00000	0.00000	1	.7	.08750	5.60000	0.0	.7	.04375	3.76250
17H	1.0	.8MV .1VB	0.0	.3QAL	.22500	.23750	1	.6	.07500	5.67500	.4	.2	.06250	3.82500
17I	.8	.5VB .2M	0.0	.1QAL	.06250	.07500	2	.3	.03750	5.71250	.1	.2	.02500	3.85000
18D	.5	MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.71250	0.0	0.0	0.00000	3.85000
18E	1.0	.5MV .5MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.71250	0.0	0.0	0.00000	3.85000
18F	1.0	MV	0.0	0.0	0.00000	0.00000	1	.4	.05000	5.76250	0.0	.4	.02500	3.87500
18G	1.0	MV	0.0	0.0	0.00000	0.00000	1	.9	.11250	5.87500	0.0	.9	.05625	3.93125
18H	1.0	MV	0.0	0.0	0.00000	0.00000	1	.5	.06250	5.93750	0.0	.5	.03125	3.96250
18I	.6	MV	0.0	0.0	0.00000	0.00000	1	.4	.05000	5.98750	0.0	.4	.02500	3.98750
19E	.5	.4VB .1MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	5.98750	0.0	0.0	0.00000	3.98750
19F	1.0	.5VB .5MV	0.0	0.0	0.00000	0.00000	1	.4	.05000	6.03750	0.0	.4	.02500	4.01250
19G	1.0	MV	0.0	0.0	0.00000	0.00000	1	.6	.07500	6.11250	0.0	.6	.03750	4.05000
19H	.7	MV	0.0	0.0	0.00000	0.00000	1	.4	.05000	6.16250	0.0	.4	.02500	4.07500
19I	.1	MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	6.16250	0.0	0.0	0.00000	4.07500
20F	.3	.2VB .1VB	0.0	0.0	0.00000	0.00000	1	.2	.02500	6.18750	0.0	.2	.01250	4.08750
20G	.8	.4VB .3MV .1VB	0.0	0.0	0.00000	0.00000	1	.4	.05000	6.23750	0.0	.4	.02500	4.11250
20H	.1	MV	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	6.23750	0.0	0.0	0.00000	4.11250
21F	.2	VB	0.0	0.0	0.00000	0.00000	1	0.0	0.00000	6.23750	0.0	0.0	0.00000	4.11250

SUM OF G= 3.70000

SUM OF M= 7.50000

SUM OF M-(XS/A1)= 5.46250

SUM OF M-(XS/A)= 5.77500

On highflight imagery, ten SSU's each 200m X 200m (labelled "a" through "j") are laid out in each PSU selected for second-stage sampling (see figure 2b.15). These SSU's are measured for g, m, and riparian vegetation area (R_1) in the same manner so were PSU's measured. Area of stream channels (R_2) is found by measurement of stream length to the nearest 100_m (r), multiplying it by average channel width (w), and dividing the result by $4km^2$ (this yields a unit compatible to R_1). The sum of R_1 and R_2 is the measure of soft ISA as seen on the highflight imagery (R_s). Data accumulated are then used to establish refined values for α, by X_s/R_s, as well as for checking accuracy of g and m. When α values have been established, the relationship between LANDSAT and highflight data may be established by a standard regression formula.

If tertiary sampling is needed, sub-sampling techniques patterned after those above may be used to select SSU's to be subsampled. Within each SSU selected, 200 meter long ground transacts should be plotted over areas of principal interest, and measured for g, m, and R_s either on low flight imagery or by ground survey. The tertiary sample data are then used to further refine secondary and primary estimations.

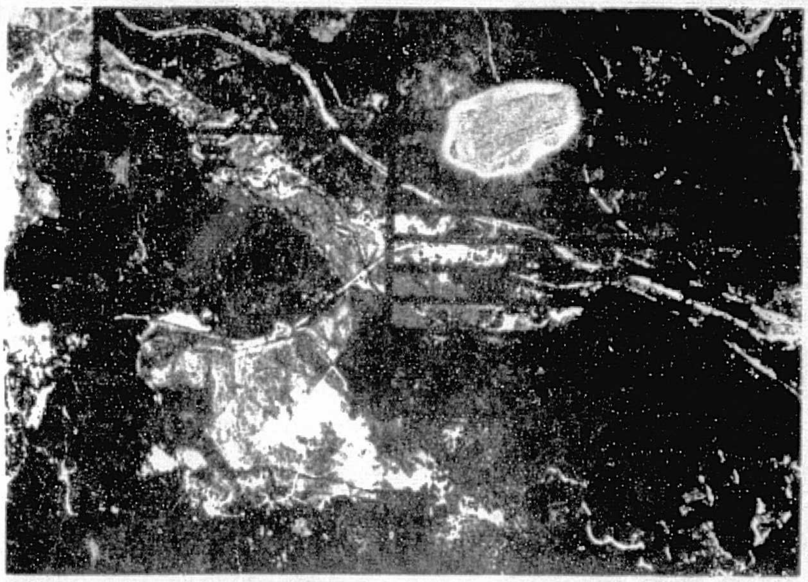
2b.4.2.6 Multi-date Procedures

A multi-date procedure has been developed to study moisture variation of meadows (P_s) over the periods of time between major precipitation inputs. Comparison of images from wet, interim and dry seasons showed significant variation in reflectance on different bands of LANDSAT imagery. By composing a color image of one band from two different dates, an image highlighting change on that band resulted.

It is important to choose LANDSAT imagery which is cloud-free for the beginning and end dates of the period of change; 10 May 73 and 13 September 73 were used for this study. It is necessary that either both images be positives or that both be negatives. To produce an accurate alignment of each image, care must be taken to prepare a stable registration base to be used to position each image during exposure. To produce the composite, it is necessary to expose one date of imagery in one color (cyan) and the other date of imagery in the complementary color (red). When printed, all areas of color will be those areas of change sought; neutral or white areas are areas of no change (very bright change areas such as snow will often appear almost white, while they are actually only overexposed cyan). A change from dark to light between May and September appears in the color of the last exposure (red). A change from light to dark (May to September) will appear in the color of the first exposure (cyan) (see figures 2b.16a & 2b.16b).

Using multi-date composites of more than one band will increase the variety of changes which may be detected. For example, changes which occur on one band only and not on the other, changes which are the same on both bands, and changes which are opposite on either band. To identify phenomena which are responsible for changes, low flight infrared imagery has the most useful detail.

Figure 2b.15



PSU 14G, with SSU's outlined, on 1 Sept 1974 color infared imagery photographed from an altitude of 65,000 feet. Note the areas of lush vegetation (bright red areas) along the stream channels and at the foot of the slopes where soil moisture is greater than in surrounding areas due to basin hydrology.

Figure 2b.16a

Band 5

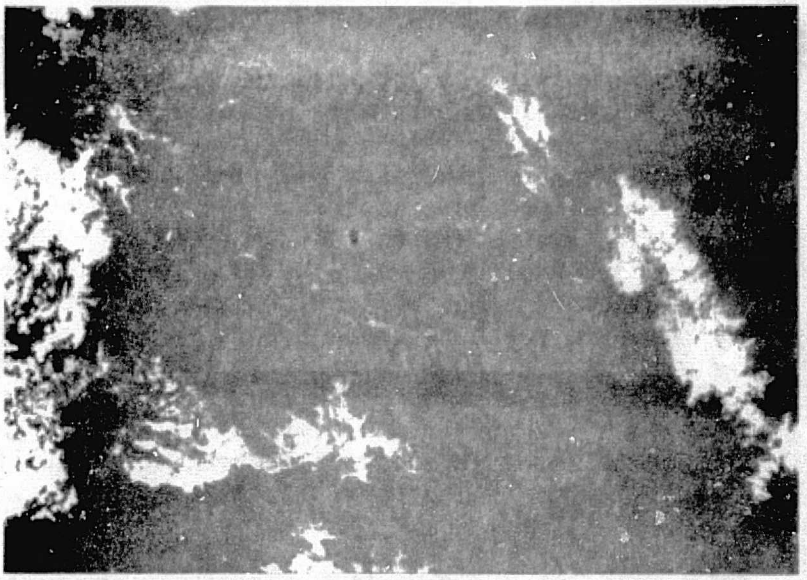
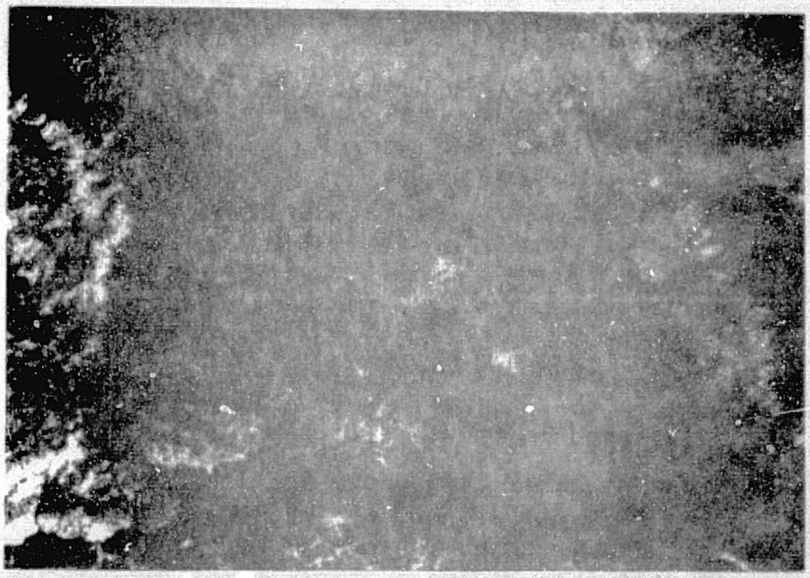


Figure 2b.16b

Band 7



Multi-date composites of 10 May 1973 with 13 Sept 1973 for LANDSAT MSS bands 5 and 7. All colors indicating change, note how a eutrophic lake (above left of center) appears bright red in both band composites, while meadow areas are red on only band 5. Similiarly, lakes frozen over in May appear in cyan on only band 7 (far left).

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There were 34 separate change areas on bands 5 and 7 for the Spanish Creek study area: twelve red areas on only band 5 (meadows); six red areas on only band 7 (shrub and brush); eight red areas common to both bands 5 and 7 (reservoir, eutrophic lake, some fields and crops); three cyan areas on only band 5 (small patches of snow); and five cyan areas on only band 7 (lakes which had thawed). Other large areas of cyan-white on both bands represented snow cover from May. Although quantification has not been done on the relative changes for each of these areas, each of the red changes represents distinctive changes in reflectance which are moisture related vegetative "flushes". The cyan areas of change are all changes in snow and ice conditions over the period of the composite. In addition to these specific areas of change, the overall tint of both bands 5 and 7 indicated a general light red change over the entire study area.[9]

Data obtained in this manner are not available through other means to the degree of detail possible here. Visual comparison of images from different dates will yield change information of only the coarsest nature; the multi-date composite yields data on even the most subtle changes and in a way that can eventually be developed to yield quantification of relative change by different color intensities. LANDSAT imagery is well suited to use in multi-date composites for two main reasons: 1) relative consistency of LANDSAT exposures over long periods of time will produce consistent multi-date images; and 2) problems with relief displacement, inherent in highflight imagery, are almost non-existent throughout the study area (42 km), and perhaps over even larger areas. In addition to these advantages, continuous new LANDSAT imagery is accumulated on every pass, providing excellent flexibility in choosing dates of input.

2b.4.3 RESULTS AND DISCUSSION

Based on the initial LANDSAT PSU sample data (g, $m\text{-}X_s/\alpha_1, X_x/\alpha_1$ shown in Table 2b.9), the Spanish Creek watershed has 3.7 units ($14.8 km^2$) of hard ISA, 5.4625 units ($21.85 km^2$) of meadow ISA less the area of stream channels and riparian growth, and 6.2375 units ($24.95 km^2$) of soft ISA, including those areas excluded above. This is a total of $61.60 km^2$ of temporarily and permanently water impervious surfaces withint the study area, or 11.49% of the watershed.

Using sub-sample selection methods described in section 2b.4.2.5 31 probability proportional to estimated size PSU's were selected for analysis on highflight imagery. Analysis of highflight SSU sample data, shown in Table 2b.10, indicated a need to use two stratified values of

[9] Great care was taken to ensure equal exposure of each date, so this general red tint is an actual indication of a general change.

α: $\alpha_2 = 8$, for major streams; and $\alpha_3 = 16$, for majority of lesser tributaries.[10] Values of X_s were identified accordingly into X_1 and X_2, as shown in Table 2b.9, and new unit values for X_s/α were computed using:

$$\frac{X_1}{\alpha_2} + \frac{X_2}{\alpha_3} = \frac{X_s}{\alpha}$$

These values of α yield an estimate of 4.1125 units (16.45 km^2) of soft ISA. The accuracy of g and m was found to be within the 0.1 (4 km^2) minimum measurement area of the PSU estimations with two minor exceptions: 0.11 units of bare rock identified in unit 10A; and 0.11 units of meadow in unit 8D. These areas had not been measured on the LANDSAT imagery, but each is just over the designated minimum area. These additions, and the use of new values of X_s/α, yield new estimates of 2.8 units (15.20 km^2) of hard ISA, and 5.875 units (23.50 km^2) of meadow area less stream channels and riparian growth.[11] This is a total of 55.15 km^2 of ISA, or 16.29% of the watershed.

Using a standard regression formula the relationship between the LANDSAT data (X_s/α) and the highflight data (R_s) was found to be the following:

$$R_s = 0.008 + 0.966\ (X_s/\alpha)$$

Applying this calculation to the soft ISA estimate yields a corrected value of 3.982 units (15.93 km^2) of soft ISA. This is the most accurate estimate possible from this procedure and yields a total measure of 54.63 km^2 of all ISA classes.[12]

10. Plotting of values of α obtained from $\frac{X_s}{R_s}$ indicated two general groups of α centered around 8 and 16.

11. 5.775 units of m - X_s/α shown in Table 2b.9 plus .1 unit in addition to the .1 unit already included for 8D, area X_s/α is already included.

12. Precisely this calculated estimate is 54.628904 $\pm$ 4.2257212 km^2, where

$$R_s = \hat{Y} = b_o + b_1(X_s/\alpha) \qquad (1)\ (1)$$

$$\hat{v}(\hat{Y}) = v(b_o) + (2(X_s/\alpha)\cdot Cov(b_o,b_1)) + (X_s/\alpha)^2\cdot v(b_1) \qquad (2)$$

$$Y\ \varepsilon\ \hat{Y} \pm t_{(n-2,\alpha=10\%)}\cdot\sqrt{\hat{v}(\hat{Y})} \qquad (3)$$

$$b_o = .008^2,\ v(b_o) = .0068^2$$

$$b_1 = .966,\ v(b_1) = .124^2$$

$$t = .1699,\ Cov(b_o,b_1) = .015$$

Quantification of multi-date imagery can yield values for p_s which can increase the seasonal accuracy for estimates of meadow area which will become impervious to water input. Moisture content of meadows (for which p_s is a coefficient) will vary over periods between precipitation inputs. As moisture content decreases, areas $(m - X_s/\alpha)$ which will become temporarily impervious will decrease. With additional development of multi-date techniques meaningful values for p_s can be obtained.

One of the advantages in using remote sensing techniques for the ISA study is the time saved over conventional ground survey methods. Time involved to analyze the 536.0km^2 Spanish Creek Watershed was 26 work hours, divided by tasks as follows:

Task	Man Hours
geologic-geomorphic stratification	6
PSU estimation of g	5
analysis of PSU data, 1st estimate	3
selection of subsample PSU's	1
SSU estimation of g, and κ	8
analysis of SSU data, 2nd estimate	3

As well as representing a significant savings in time, use of remote sensing techniques for geologic stratification improved the delineation accuracy of many geologic boundaries shown on the 1:250,000 scale maps used in this study, for which large areas were last mapped during the 1890's.

2b.4.4 CONCLUSIONS

This investigation has developed a technique for quickly utilizing available LANDSAT data to estimate ISA in a manner compatible to use in other water outflow studies. Based on the methods described, an ISA estimation for an area of this size may be done within a period of 10-12

Table 2b.10 Highflight SSU Sample Data

$R1$ = sum of SSU measures for a through j.

r = length of streams in PSU (x 100m).

$$R2 = \frac{r(100m) \times w}{4km^2}, (w = 5m).$$

$$Rs = R1 + R2$$

unit	g	m	R1	r	R2	Rs	X_s/α
2G			.015	42.0	.00525	.02025	.01875
5G		.02	.05	61.8	.007725	.057725	.025
5H		.28	.09	51.6	.00645	.09645	.0875
6F	.01		.07	73.8	.009225	.079225	.05
6G	.06		.035	78.0	.00975	.04475	.04375
6I		.16	.025	48.0	.006	.031	.06875
7F	.19	.03	.085	24.0	.003	.088	.075
7I			.055	66.0	.00825	.06325	.04375
8D		.11	.08	18.0	.00225	.08225	.0625
9C			.035	54.0	.00675	.04175	.04375
10A	.11		.02	25.8	.003225	.023225	.0375
10C			.04	43.8	.005475	.045475	.03125
10D			.08	49.8	.006225	.086225	.08125
10D			.08	49.8	.006225	.086225	.08125
10F		.19	.06	30.0	.00375	.06375	.05625
10F		.19	.06	30.0	.00375	.06375	.05625
10I			.03	33.6	.0042	.0342	.03125
11F	.03	.61	.03	42.0	.00525	.03525	.0625
13D	.09		.04	73.8	.009225	.049225	.04375
13D	.09		.04	73.8	.009225	.049225	.04375
13E		.04	.065	60.0	.0075	.0725	.0625
13F		.07	.08	54.0	.00675	.08675	.06875
14G		.175	.095	37.8	.004725	.099725	.0875
14G		.175	.095	37.8	.004725	.099725	.0875
15H			.035	36.0	.0045	.0395	.0375
16G			.015	30.0	.00375	.01875	.025
18G			.05	54.0	.00675	.05675	.05625
19G	.01		.05	60.0	.0075	.05675	.0375
19G	.01		.05	60.0	.0075	.0575	.0375
20F			.02	18.0	.00225	.02225	.0125
20G			.02	36.0	.0045	.0245	.025

work hours; ISA estimations to be used in a PSA study may require somewhat longer, but still remain within a period of 24-26 work hours. Neither of these estimations include acquisition of ground truth data or time spent locating and processing imagery, each of which consumes a greater portion of time than the actual analysis. In addition, each will vary considerably with one's "on-hand" available resources.

This study has estimated 54.63km^2 of permanently and temporarily impervious surface areas within the 536.0km^2 area of the Spanish Creek Watershed. Application of these data to water outflow models will be a step toward increasing the accuracy in water resources management.

2b.4.5 FURTHER WORK BEYOND THE ISA STUDY

This study has initiated developments in applications and analysis of LANDSAT imagery in three areas beyond the scope of the ISA study:

(1) geologic-geomorphic stratification of the study area, using LANDSAT imagery, with potential application of techniques to automatic analysis.

(2) development of a new technique of multi-date analysis.

(3) conduct of pervious surface area (PSA) study utilizing LANDSAT data, and resulting in the construction of a water outflow model for automatic analysis.

Each of these areas has important applications beyond the scope of this study and may be developed individually. While much work has already been done with geologic stratification and identification in specific locales, the procedures have not been fully developed for broader survey applications. Similar situations to a lesser, rudimentary degree exist for each multidate analysis and the PSA estimation procedures. Additional work could be done to develop each of these areas.

Development of each of the three areas listed above is recommended, with emphasis on the PSA study as it relates to the work designated under RSRP's water yield estimation research goals for this NASA grant. Multi-date techniques also offer broad potential applications to the PSA study, as well as to any field potentially interested in change detection analysis. Geologic-geomorphic stratification, while completed for the Spanish Creek Watershed, may be further refined through automatic analysis. Full development of such techniques has potential application to large scale resource exploration and mapping of regions of the world which are either poorly mapped or essentially unmapped.

2b.5.1 SUMMARY/CONCLUSION

This investigation suggests that remote sensing promises great potential for predicting water-yield and aiding water resources management. The findings of the NASA-Grant research conducted under our Remote Sensing Research Program at U.C. Berkeley would be directly applied to the Sacramento Hydrologic Model of the California Joint Federal-State River Forecasting Center (RFS) and to the California Cooperative, Snow Survey (CCSS) volumetric and dynamic water yield models.

The methodology has been developed for a remote sensing-aided system to estimate the various components of a water yield model that is designed to give timely, relatively accurate, and cost-effective estimates over the watershed(s) of interest. These components are snow areal extent, snow water content, water loss to the atmosphere (evapotranspiration) and impervious surface area. The system employs a basic two stage, two phase sample of three information resolution levels to estimate the quantity of the above-mentioned water-yield model components.

The input data for this system requiring spatial information are provided by LANDSAT, by environmental (meteorological) satellites, by high and low flight aerial photography, and by ground observation.

In the case of snow areal extent estimation the manual phase has been completed. This technique may be considered operational depending on the user's needs. Based on the results obtained when using this technique, it can be concluded that potentially there is a substantial advantage in terms of both cost-effectiveness and precision to be gained through use of this remote sensing-based technique to other, conventional methods. Further investigations in automatic analysis of the areal extent of snow as well as the refinement of the manual technique are needed. This would allow the user a choice of the level of sophistication that he desires or can afford.

From the results obtained in our snow water content study to date it can be shown that a potential cost and/or precision advantage is also to be gained in this area by use of remote sensing-aided methodology. Our method utilizes data obtained through conventional ground measurement of snow courses integrated into a double sampling framework with LANDSAT-derived data. Further investigation on optimizing image sample unit size and automatic analysis would improve the precision of the snow water content estimates over the watershed.

The development of Level I, and Level II models for watershed-wide estimation of evapotranspiration has been completed and currently

Watershed for efficiency testing purposes, but will be expanded to include ultimately the entire Feather River basin.

3. Development of an automatic (computerized) system for watershed-wide integration and interpolation of point data. This system would estimate the distribution of point data (i.e. precipitation) over the watershed of interest. The point data include the input and output parameters used in snow areal extent, snow water content, and evapotranspiration models.

4. Sensitivity analysis for critical parameters in water supply models. In coordination with the Algazi Group, RSRP is developing water parameter (water loss) estimates to be included in current RFC and CCSS hydrologic models. The performance change in the models with and without these remote sensing-aided estimates as determined on the Davis system will be noted. Feedback on model performance will allow modification of the remote sensing-aided water parameter estimation sampling design and methodology so as to improve hydrologic model performance.

5. Determine the costs of information-gathering using conventional and remote sensing-aided methods. This effort continues especially in the context of the RFC Sacramento River model and the CCSS volumetric model. Cost data on semi-automatic/automatic remote sensing-aided basin snow areal extent, snow water content, evapotranspiration, and manual impervious surface area estimation is especially emphasized.

6. Perform cost-effectiveness analyses with respect to conventional and remote sensing-aided water supply estimation systems. In the near run,systems for estimation of intermediate parameters used in ultimate water yield prediction will be compared. In the longer run, systems actually producing water runoff estimates will have comparitive analyses performed. Coordination here will be especially strong between RSRP and Social Science Group personnel.

7. Contribute to cost-benefit studies to determine the impace on society resulting from changes in water supply information caused by the application of remote sensing techniqu o water supply models. RSRP will contribute cost and performance data, in conjunction with the Algazi Group, to the Social Sciences Group for cost-benefit impact studies.

level I ET models are being applied to the Spanish Creek Watershed. A necessary documentation of assumptions, structure and limitations of current evapotranspiration models has been established. Based on this analysis and the results obtained from the application of level I and level II ET models, the appropriate model(s) to be applied in the third level of ET modeling will first be developed and examined for the Spanish Creek Watershed and then applied to the entire Feather River Watershed.

The technique for estimation of impervious surface area (ISA) has been developed and applied to the Spanish Creek Watershed. This technique has been designed to be timely, cost-effective, and relatively accurate. The estimates of permanently and temporarily impervious surface areas over the Spanish Creek Watershed have been made and further investigation is needed for expansion of the study area to the entire Feather River Watershed, with a view to applying ISA results in outflow water prediction models, and improving the overall accuracies of the results obtainable by such means.

2b.5.2 CONTINUED RSRP GRANT WATER SUPPLY WORK

The seven continuing aspects for this work are as follows:

1. Continued state-of-the-art water supply model definition and performance documentation. This effort, carried out in conjunction with the U.C. Davis, Algazi Group, is necessary to fully refine the remote sensing-aided water loss estimation procedures and the set of variables considered. Both the California Joint Federal-State River Forecasting Center (RFC) Sacramento hydrologic model and the California Cooperative Snow Surveys (CCSS) hydrologic models continue to be examined. Performance documentation continues for the CCSS models and performance for the RFC model will be stated concisely in the context of the forecast assumptions.

   Inspection of current water quality prediction methodologies may also be begun. As stated in Chapter 2a and Chapter 5, the water quality question is of growing importance in wat.r resources management, and especially in managing the California Water Project. Water quality determination and prediction is thus a viable subject area for potential analysis in the current NASA sponsored study.

2. Continued development and testing of the remote sensing-aided water loss estimation system. This work includes refinement of sample design plus technique development for estimation of watershed snow areal extent, snow water content, evapotranspiration, impervious surface area, and effective precipitation input. The data set initially includes the Spanish Creek

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APPENDIX I

THE PHOTOGRAPHIC CONSTRUCTION OF LANDSAT COLOR COMPOSITE IMAGERY

INTRODUCTION

The value of color composites has long been recognized as an aid to the interpretation of LANDSAT imagery. The technique described in this appendix demonstrates how LANDSAT color composite imagery can be constructed from LANDSAT positive black-and-white transparencies conveniently and inexpensively.

COLOR COMPOSITE THEORY

Typical color reversal and color negative films consist basically of three light sensitive layers. These layers react individually to blue, green, and red light, each layer corresponding to a particular dye, dependent upon film type, as indicated below:

Light Sensitivity	Color reversal film Dye layers activated	Color negative film Dye layer activated
Red	Yellow and Magenta	Cyan
Green	Yellow and Cyan	Magenta
Blue	Magenta and Cyan	Yellow

If, for instance, color negative film is exposed to blue light, the blue sensitive layer of the film is activated while the other layers remain unaffected. This blue-sensitive layer corresponds to a final yellow dye image and hence the results will appear yellow on the negative.

When color reversal film is exposed to blue light, the blue sensitive layer of the film is activated; however, during processing the two remaining sensitivity layers corresponding to the magenta dye (green sensitive) and the cyan dye (red sensitive) are either chemically or mechanically exposed. The original exposed blue sensitive layer becomes non-functional and the resulting image appears blue due to the combination of magenta and cyan dyes. The reactions of color reversal and negative film to red and green light can be explained similarly since red is produced by a combination of yellow and magenta dyes and green is produced by a combination of cyan and yellow dyes.

The photographic construction of LANDSAT color composites relies on the three-layer sensitivity of color film and on the different densities of any given feature as it appears on the various LANDSAT black-and-white bands. Each of the different LANDSAT black-and-white bands chosen to

make the color composite is photographically copied onto the same sheet (or frame) of color film, each band through a different colored filter (in essence a multiple exposure). Figure 1 illustrates the set-up used to produce LANDSAT color composites. Depending on which filter is used with each band of imagery different color renditions may be produced, hopefully enhancing different features.

MATERIALS AND EQUIPMENT

Landsat Black-and-White Imagery

The construction of LANDSAT color composites commonly uses Multispectral Scanner (MSS) imagery of bands 4, 5, and 7, usually in the 9½ inch positive transparency form (although the 70 millimeter positive transparencies may also be used). MSS band 6 is also used for some composites as well as available Return Beam Videcon (RVB) positive imagery. Furthermore, just as a color composite can be formed by combining bands of imagery acquired on a single date, so it also can be formed by combining several dates of imagery acquired in a single band, or any combination of multiband/multidate images.

FILTERS

Eastman Kodak Wratten filters are suggested for use in the construction of color composites due to their optical quality and the large variety of colors and sizes available. To produce a simulated false-color infrared color composite image, Wratten filter numbers 25 (tricolor red), 47B (tricolor blue), and 58 (tricolor green) can be used.

FILTER RELATED ACCESSORIES

Eastman Kodak filter frames provide a convenient way to mount the Wratten filters. The filters so mounted can be easily inserted onto a commercially available filter holder which mounts, via adapters, to the filter-threaded receptable in the front of most enlarging lenses.

PHOTOGRAPHIC LIGHT SOURCE

The light source is used to provide the light which will be transmitted through the LANDSAT bands during the exposure process. Basically, the light source may be of two common types; incandiscent or flourescent and electronic strobe. Incandescent or flourescent illumination in the form of a "light table" may be the most convenient form initially. One of the problems encountered with using a light table is its relatively low light output, necessitating long exposures times. One way of countering this is by using an electronic strobe light box which would give decidedly greater light output and thus shorter exposures.

REGISTRATION SHEET

The registration sheet is used to register the individual LANDSAT bands with respect to one another. It also serves as a convenient base for introducing grids or other data directly on the color composite. The material used for the registration base should be translucent (frosted preferably), dimensionally stable and have a surface ammenable to scribing. Keuffel and Esser Stabilen Cartographic Drafting Film, base thickness 7 mil satisfied these criteria, and has been used usccessfully for constructing color composites.

SCRIBING TOOLS

The scribing tools consist of a scriber and a metal straight edge. The scriber can be constructed by inserting a drafting compass needle in an engineering drafting pencil while the metal straight edge may simple by a metal engineering scale. The scribing tools are used to transfer the LANDSAT registration marks onto the registration sheet.

CAMERA SYSTEM

A large variety of cameras and related accessories ranging in format from 35 millimeter to much larger image sizes can be used to construct LANDSAT color composites. The only requirement is that the camera be capable of making accurate multiple exposures on a single sheet or frame of film. The most convenient camera used to develop this system was found to be a type of copy camera which utilizes a leaf shutter system allowing as many exposures as desired on a single sheet or frame of film. A camera system of this type is desirable due to its ability to accept film formats from 35 millimeters to 4 x 5 inches.

The camera lens used for making color composites should be of very high quality. Since the construction of color composites utilizes most of the light-sensitive spectral range of conventional color film, the lenses used should be color corrected. The lenses should be of very high uniform edge-to-edge resolution and contrast to assure that no information is lost throughout the image area. Schneider Componon Enlarging lenses have been used with great success as shown in figures 3 and 4.

EXPOSURE METER

An exposure meter should be used to determine how much exposure should be given to each of the LANDSAT black-and-white images in making the color composite. The meter used should have a locking needle, a wide sensitivity range and a narrow acceptance angle so that selective area measurements can be made. The Gossen Luna-Pro light meter with the optional acceptance angle attachment has been used successfully for light measurements off the camera system's ground glass.

FILM TYPES

If reflection prints are to be made of the color composite, it is most convenient to use a fine grain negative color film such as Kodak Vericolor II Type S. If positive color transparencies are desired (e.g. for projection purposes) the use of either Kodachrome or Ektachrome film is appropriate, depending on the film format used.

PROCEDURE

The following step-by-step description will detail the procedure used to construct a LANDSAT color composite.

1. Tape one band of a LANDSAT black-and-white set of imagery for a specific date to a light table in proper viewing position.

2. Tape a sheet of K&E Stabiline over the LANDSAT image so that the four registration marks (+) in the corners of the LANDSAT image are completely covered by the overlying sheet.

3. Transfer the registration marks to the Stabiline using the scribe and the metal straight edge. The scribed line should be narrow in width and extend beyond the actual LANDSAT registration marks to facilitate the actual registration process.

4. The registration sheet (Stabiline) should be labeled with the latitude/longitude and date of the LANDSAT imagery from which it was made. This information is placed on the same edge as observed on the LANDSAT image below so that the LANDSAT black-and-white bands may be oriented correctly during the registration process.

5. The completed registration sheet is removed and placed in proper position of the light table or flash box and taped down.

6. One of the LANDSAT bands to be used for making the composite is taped down in register over the registration sheet. The registration marks and the information line are used to register and orient the two, relative to one another.

7. The camera system is focused upon this registered image and locked into position.

8. An exposure measurement of the LANDSAT band is then made on the ground glass focusing screen of the camera with the lens set at a fixed aperture, usually maximum. This reading is recorded. The other LANDSAT bands to be used are then placed one at a time on the registration sheet with the image projected onto the focusing screen and the exposure measurement for each is recorded again at the same fixed aperture.

9. The exposure measurements for the LANDSAT bands are averaged and refered to exposure graphs (which are explained in the next section).

10. The camera/lens exposure controls are then set according to the exposure graphs.

11. The film on which the composite is to be made is then loaded in the camera.

12. One at a time, the LANDSAT bands are placed on the registration sheet and exposed through the appropriate filter. The film is not advanced or removed until all exposures have been made.

13. The film is then processed normally yielding the final color composite.

EXPOSURE DETERMINATION

In determining the proper exposure to give each of the LANDSAT black-and-white images the separate bands are assumed to be matched separation positives. The actual deviation from this assumption is generally so slight that it may be ignored in most if not all cases.

Since no two light source systems developed to construct LANDSAT color composite imagery will have equal light outputs, the graph used to determine proper exposure must be empirically established. The following describes the determination of the exposure graph necessary for proper exposure calculation. Since each exposure graph can be calculated for one particular color composite type (i.e., band/filter combination) only, the following description will deal with the construction of a simulated false color infrared composite. To make this particular rendition LANDSAT band 7 is exposed through a Wratten 25 (Red) filter, band 5 through a Wratten 58 (Green) filter and band 4 through a Wratten 47B (Blue) filter.

To determine empirically the exposure graphs for the various band/filter combinations, a series of color composite are constructed at different overall exposures. Each series of color composites has exposure values measured for each band as per step 8 under "procedures". The values measured are averaged for each set and then plotted versus the actual overall exposure found to give an acceptable color composite. All light measurement values are taken with the lens set at a fixed aperture. This aperture will always be used for the through-the-lens exposure measurement of each band. This is necessary to provide a consistent index system for reference to the exposure graphs.

The averaged exposure measurements taken from the individual LANDSAT bands are plotted on the x-axis versus Exposure Values (EV) on the y-axis. EV refers to equal light intensities; hence equal combinations of shutter speed and aperture which yield the same exposure to the film. For example, EV 13 equals 1/30 second at F/15, 1/60 second at f/11, 1/125 second at f/8, 1/250 second at f/5.6, etc. Figure 2 illustrates the appearance of such an exposure graph.

Due to the different optical densities of the filters used to construct a color composite, different exposures are needed for each band/filter combination. These different densities are refered to as filter factors. The filter factor for a given filter changes with the film type as well as the light source; consequently filter factors must be calculated for each film type/light source combination. One practical way of calculating specific filter factors is to photograph a transparent gray scale through each of the filters for which the filter factor is to be determined. These will produce individual exposures through the filters onto color film, either positive or negative. Several exposures are taken through each filter, advancing or changing the film after each exposure. All exposures must be recorded for the final determination of the filter factors. For each filter an exposure is found which best reproduces the gray scale (i.e. all gray levels are clearly distinguishable from each other) by examining the color film. In all cases each individual gray level should have the same optical density for all of the filter types used. This is best done through the use of a densitometer but can be done visually if necessary. A comparison of the exposures used for the various filters to obtain equal densities gray level-by-level, will give the filter factors for each filter. These filter factors may then be translated into EV's to give the relative exposure differences for the filters used.

To establish the exposure graphs for the various band/filter combinations, a series of color composites are constructed, all at different overall exposures. Each composite so constructed must have the filter factors (in terms of individual exposure differences) included. If, for example, for a specific film/light source combination, it is determined that a Wratten 47B filter requires 1 EV more exposure than a Wratten 58 filter (which requires itself ½ EV more exposure than a Wratten 25 filter to obtain equal density levels) then a series of exposures can be made using these differences. For the first composite the overall exposure might be EV13 through the Wratten 47B filter, EV 14 through the Wratten 58 filter, and EV 14.5 through the Wratten 25 filter. For the second composite overall exposure might be EV14 through the Wratten 47B filter, EV 15 through the Wratten 58 filter, and EV 15.5 through the Wratten 25 filter and so on. Since the individual filters require different but equal relative exposure differences maintained during the construction of the composites, color balance is kept stable, but overall composite density is not. Thus the best composite density from this series of different overall exposures can be determined. By plotting the exposures used for each filter in the best

composite constructed, one group of points may be plotted on the exposure graph for this particular band/filter combination. Once two groups of points, each representing a good color composite overall exposure for a specific band/filter combination have been plotted, the graph can be completed.

CONCLUSIONS

Several critical points are worth mentioning again to assure that the color composites are correctly constructed:

1. During the actual photographic construction, several exposures are made on the same sheet or frame of film; the film is not removed or advanced during these exposures.

2. All exposure measurement values of the various bands are made through the camera/lens assembly on the ground using a fixed aperture. This aperture may change depending upon the actual responses of the various bands during the copying process.

3. The individual exposure measurements of the bands to be used are mathematically averaged and then refereed to the exposure graph for the exposure setting of each band/filter combination.

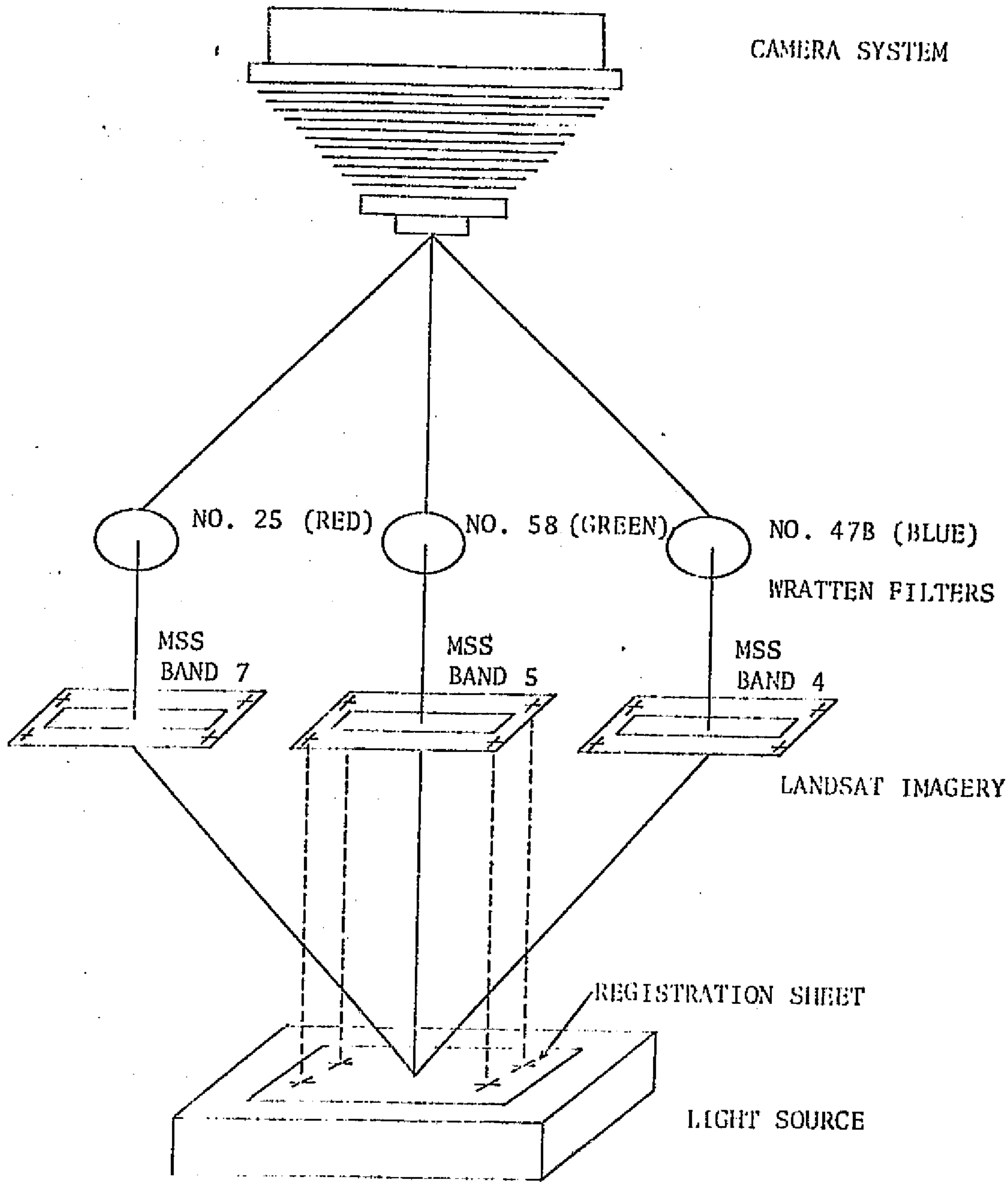

Figure 2b.17 This schematic diagram illustrates the photographic technique for constructing color composite images. A camera, color film, colored filters, LANDSAT imagery, a registration sheet and a light source are employed. Note that all three bands are placed separately on the registration sheet for copying. The band/filter combinations shown in the diagram above are used to produce simulated false color infrared composites. Different band/filter combinations will rpoduce differently colored composites.

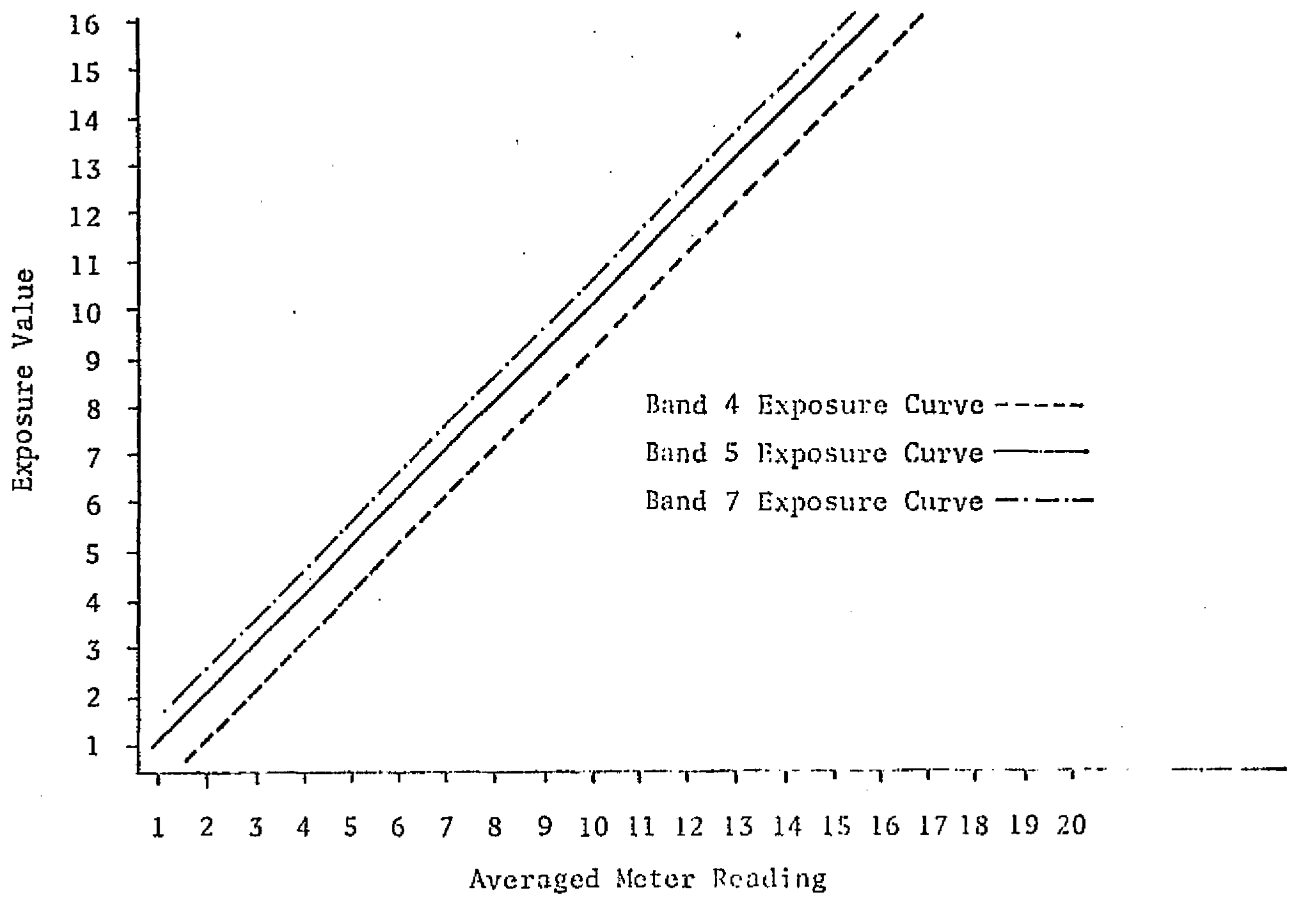

Figure 2b.18 Example exposure data for the construction of a simulated false-color infrared three band color composite using a conventional light table or a flashbox. LANDSAT MSS Band 4 is combined with a Wratten 47B filter, Band 5 with a Wratten 58 filter, and Band 7 with a Wratten 25 filter. Different exposure curves must be derived for different film speeds and/or different band/filter combinations, as explained in the text.

*Exposure values (EV) are those unique combinations of shutter speed and aperture which yield the same exposure. For instance EV 13 represents the combinations 1/125 second at f/8, 1/60 second at f/11, 1/30 second at f/16, etc.

Chapter 3

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Chapter 3

WATER DEMAND STUDIES IN CENTRAL CALIFORNIA

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Contributors: John Jensen, Larry Tinney, Sue Atwater, Tara Hardoin, Don Hoffman, Iris Priestaf, Brad Yackle

3.00 INTRODUCTION

During the current reporting period, the Geography Remote Sensing Unit, University of California, Santa Barbara has been concentrating its research effort on the following water demand related topics:

- An analytical and empirical analysis of those variables which have a significant affect on a remote sensing agricultural water demand prediction procedure;

- The development and/or refinement of manual and semi-automatic remote sensing techniques to extract data relevant to these variables;

- Comparison of remote sensing techniques for acquiring information on specific water demand related parameters with conventional methods to draw conclusions regarding cost-effectiveness;

- An experimental water demand prediction for Kern County Water Agency hydrologic model nodes in the Wheeler Ridge-Maricopa Water Storage District to assess the semi-operational utility of proposed remote sensing procedures;

- Initiation of research to determine whether water demand prediction procedures created for a semi-arid environment can be effectively applied in more temperate climatic regions, requiring slightly different water demand parameters.

In essence, these subject areas represent research on work items 1, 4, 5, and 6 of the chronological work plan seen in Table 1. As discussed in section 3.5 of this report, research on parameters associated with croptype have only recently reached a point where valid assessments can be made concerning the economic impact of using remote sensing data in the Kern County Water Agency (KCWA) hydrology model. In effect, work items 2, 3, and 7 will begin to be realized as the more accurate croptype water demand predictions are input to the model and cost-benefit analyses applied.

Work Item	Investigators	75 / 76 M J J A S O N D J F M A	77 M J A S O N D J F M A
1. Determine critical parameters in water demand models	Riverside Santa Barbara Burgy	Technically Completed	
2. Analyze economic impact resulting from changes in water demand information	Public Policy Riverside Santa Barbara Hoos Economist Lawyer		
3. Compute economic effects of changes in estimation of critical parameters	Riverside Santa Barbara Economist Hoos		
4. Evaluate and test remote sensing techniques	Riverside Santa Barbara RSRP		
5. Determine costs of information-gathering using conventional methods	Riverside Santa Barbara		
6. Compare remote sensing techniques with conventional ones. Draw conclusions regarding cost-effectiveness	Riverside Santa Barbara RSRP Economist		
7. Estimate potential impact of using remote sensing techniques in water demand problems	Riverside Santa Barbara RSRP Economist Hoos Burgy		

TABLE 3-1. Chronological Work Plan for Assessment of Water Demand in Central California by means of remote sensing.

3.10 WATER DEMAND RATIONALE

3.11 Introduction

A careful review of references related to future predictions i.e., Hudson Institute, RAND, TEMPO, Club of Rome, etc., indicate a nearly unanimous opinion that the effects of world exponential population growth will impact all mankind before the end of the 20th century. The following will most probably occur during the 1980 to 2000 time period:

- World population will increase from 3.2 billion (1973) to approximately 7 billion (2000) creating intensified land use pressures and a growing list of critical short mineral resources.

- International trade of all types will reach a new high, with particular increases in the areas of foodstuffs, minerals, and energy.

- International cooperation in agricultural production and marketing will be widespread, as the world seeks to maximize its ability to feed itself.

- Government funded research and development (R&D) coupled with the use of large scale modeling data bands will increase in societies, such as the U.S., where government is expected to act as the catalyst to conduct resource and ecological surveys.

3.12 Agricultural Water Demand

Food and energy production are identified by many as primary research frontiers for the coming decades. If we are to maximize agricultural production to meet future demand it will be necessary to have almost real-time statistics on agricultural water supply and demand on a regional, state, national and even international basis. It is this basic need for data which lead the investigators conducting the recently published TERSSE study (Total Earth Resource System for the Shuttle Era)[1] to identify two of 30 priority TERSSE missions as being:

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[1] The basic criterion for the inclusion of a mission was that there be a reasonable chance of the mission being performed during the 1980's time frame under consideration. Definitionsof the 30 missions were based on the following inputs to the study: 1) mandated tasks of Major Federal Organizations; 2) information requirements of the Other Dominant Organizations; and 3) assessments of the relative amenability of the information classes to remote sensing. On the basis of a review and evaluation of these inputs a list of 30 basic TERSSE missions was synthesized. General Electric Space Division, Definition of the Total Earth Resources System for the Shuttle Era. Philadelphia: General Electric, Vol. 3, (Nov. 1974), p. 3-11.

- Survey and monitor U.S. cropland to calculate short-and-long run *demand* for irrigation water.

- Survey and inventory the volume and distribution of surface and groundwater to assess available *supplies* for urban and agricultural consumption.

The TERSSE study is interesting because it reveals that remotely sensed irrigation water demand prediction techniques must be developed whereas urban water demand is not defined as a unique study area, even though its existence is alluded to in the water supply mission. The reasons for the deletion of the urban water demand prediction methodology stem from the unusually precise meter data already available from most municipal water and power companies. New urban water estimates can be rapidly obtained through interrogation of historical meter statistics and analysis of newly zoned and/or built urban structures. The actual prediction of urban water demand is, therefore, much more stable and, in fact, much more predictable than agricultural water demand. By putting priorities in their proper perspective it can be seen that if the urban water demand prediction is all but available, then it is only reasonable to expend the maximum research effort identifying those parameters which facilitate the accurate prediction of dynamic agricultural water demand. This demand, in turn, is positively correlated with the agricultural yield of a given region.

3.13 Kern County: Agriculture, Water Demand, Hydrology Modeling

In order to develop a remote sensing irrigation water demand prediction methodology a representative region was located which possessed a sufficient range of environmental parameters, both physical and cultural, to accurately gauge the success of the proposed techniques. Kern County, California, is one of the major agricultural counties in the United States with an estimated value of direct farm marketings in 1974 of over $700,000,000. This production is primarily dependent on the irrigation of about 356,000 harvested hectares (880,000 acres).[1] To support this level of agricultural production, Kern County will consume over 660,000 acre-feet of California Aqueduct water alone in 1975. This consumption will be at a mean cost of $20 per acre-foot for the 16 water districts within the county. Imported water from the California Aqueduct only supplements an annual groundwater extraction of approximately two million acre-feet, or about four times that amount being imported by the state project. Kern County's continued demand on its groundwater resource, at rates exceeding the safe yield, has resulted in a continuous decline of groundwater levels over most of the county. For example, during 1972 unconfined water

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[1] Stockton, James W., 1974 Annual Crop Report for the County of Kern. Bakersfield: U.S. Department of Agriculture, 1975, p. 1-5.

elevations declined 6, 9, 12, and 29 feet at the Vista, Semitropic, Kern River Delta, and North Kern Water Storage Districts, respectively.[1] It is anticipated that the rate of this overdraft will be reduced as water districts overlying the groundwater basin increase their use of California Aqueduct water and decrease their use of groundwater.

Analysis of projected California Water Project deliveries by use for Kern County through 1990 (Figure 3-1) illustrates that irrigation water and groundwater replenishment account for approximately 84% and 11% of the Kern County Water demand respectively. The urban-industrial, recreation including fish and wildlife sectors demand the remaining 5% of the Kern County 1990 water requirement. Even with the maximum supplies of imported state water contracted for in 1990 (the demand for which will be realized as early as 1980) Kern County will be overdrafting its basin if irrigated agricultural lands are expanded beyond their present areal extent. The situation is critical and the potential benefits which may occur as a result of increased efficiencies, derived through the utilization of remote sensing techniques, could be significant.

The interface of remote sensing-derived information with the present Kern County groundbasin model should facilitate a near real-time prediction of agricultural water demand, thus enabling the Kern County Water Agency to anticipate:

- the total amount of water demand (ground and/or imported) on a seasonal basis;
- the amount of imported water available and/or demanded for groundwater replenishment;
- possible water exchanges and rerouting alternatives.

The implementation of such a near real-time water management system could provide significant dollar benefits to Kern County.

Prior to the interface with GRSU, the KCWA in cooperation with the State of California, Department of Water Resources (DWR), realized the need for a water demand forecasting capability and contracted with TEMPO[2] to develop a digital computer model of the groundwater basin. This model was initially driven by historical data and relied heavily on agricultural land use data derived from terrestrial surveys. The GRSU has critically analyzed the KCWA hydrology model and identified those model parameters directly amenable to remote sensing. These parameters are depicted in

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1 Kern County Water Agency, Annual Report - 1972 and 1973. Bakersfield: KCWA, 1974

2 TEMPO, Center for Advanced Studies of Santa Barbara, California, a subsidiary of General Electric.

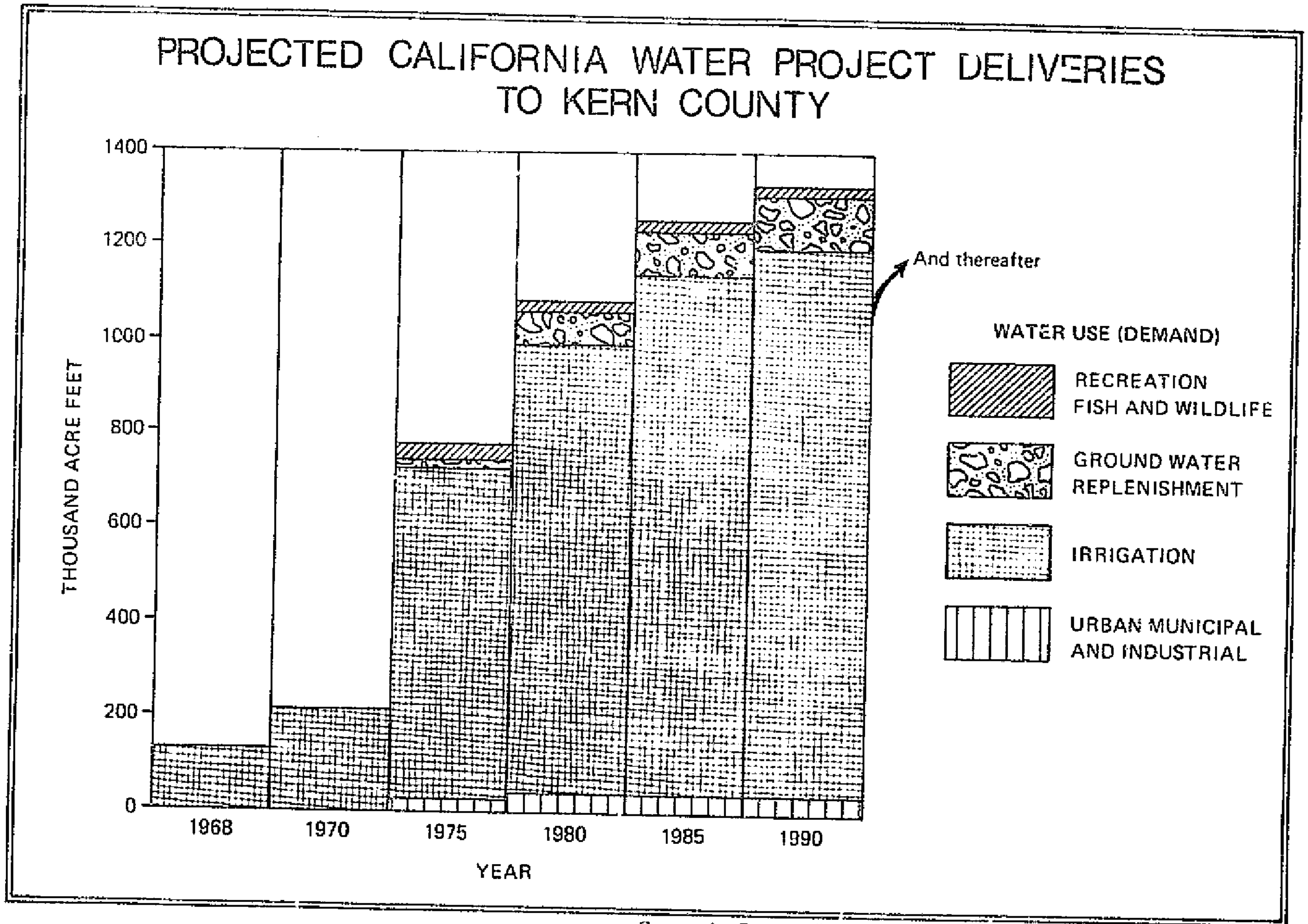

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Figure 3-1. By 1990, irrigation water use in Kern County will account for approximately 84% of projected water deliveries from the California Water Project while groundwater replenishment will account for some 11%. Recreation (including fish and wildlife) and urban municipal and industrial uses account for the remaining 5%.

Table 3-2.

By identifying those input parameters amenable to remote sensing and in turn concentrating on those parameters which carry the most leverage in the water demand prediction, GRSU began to develop remote sensing techniques and methodologies to meet the KCWA models' data requirements. In the near future data derived from remote sensing will be utilized in a dedicated model run and the results compared to a similar run based solely on conventionally derived data (see Appendix I). The results of such a comparison, if an increase in prediction accuracies can be demonstrated, have important implications. For example, there are currently about 900,000 acres under irrigation in Kern County out of 1,600,000 potentially irrigable acres. The countywide crop value for a section of land (640 acres) is approximately $500,000 ($800 crop value/acre x 640 acres/section). Therefore, in principle, for each 1% of increased efficiency in the application of irrigation waters that result from the use of improved data in the hydrologic model, approximately 12.5 additional sections could be brought into production. An addition of this magnitude would represent a crop value of approximately $6,250,000 dollars. In addition, although some comparative cost analyses between conventional and remote sensing techniques have been documented (e.g., cropland inventories), a substantial research effort is currently being directed at determining the cost-effectiveness of the remote detection of several other parameters i.e., croptype, soil salinity, and perched water. It is hypothesized that in addition to being cost effective in their own right, several of these remote sensing procedures may also help increase the efficiency of mandatory terrestrial data surveys by creating a more accurate stratification plan for sampling or mapping.

GRSU research on the development of remote sensing techniques for the generation of water demand statistics is leading to a remote sensing/user agency data flow as illustrated in Figure 3-2. In this capacity, remotely sensed agricultural acreage and its inherent components (i.e., croptype, fallow, double cropping, etc.) are extracted (classified) primarily from LANDSAT data which has had supervised training sets defined. The irrigation rates from auxillary data are refined through remote sensing (i.e., croptype, pre-irrigation, salinity leaching requirement). These two data sets are then interrogated to yield the output irrigation water demand prediction statistics. These statistics are then used by the user agencies, i.e., KCWA, Water Storage Districts, agribusiness concerns, etc. to optimize the water management decisions discussed earlier.

The following sections will discuss GRSU's research conducted to further evaluate the components within the acreage and irrigation rate water demand parameters. The current status of the remote sensing inventory techniques will also be discussed, as they relate to a semi-automated irrigation water demand prediction for a portion of the Wheeler Ridge-Maricopa Water Storage District in Kern County.

TABLE 3-2. Kern County Water Agency: Critical Hydrology Model Inputs Amenable to Remote Sensing.

EXTERNAL QUANTITIES	DEFINITION	SOURCE(S)	REMOTE SENSING CAPABILITIES (IDENTIFY-MEASURE)
Agriculture Useage			
gross irrigated acres	total amount of irrigated acreage	periodic air surveys modified in districts	irrigated croplands
unit agricultural consumptive use	acre-feet water requirement by individual crops for evapotranspiration	Department of Water Resources, experimentation with individual crops	crop identification
Surface & Groundwater Movement			
volume of moisture deficient soil	volume of unsaturated soil	calculated from field work (soil surveys)	soil moisture
% to perched water table	% of node overlying perched water table x nodal deep percolation	field investigations	perched water table areas
External Quantity not yet Incorporated into Model			
soil salinity	soil salinity (electrical conductivity) and the leaching requirement in acre-feet	field investigation	salinity damage assessment; soil salinity prediction

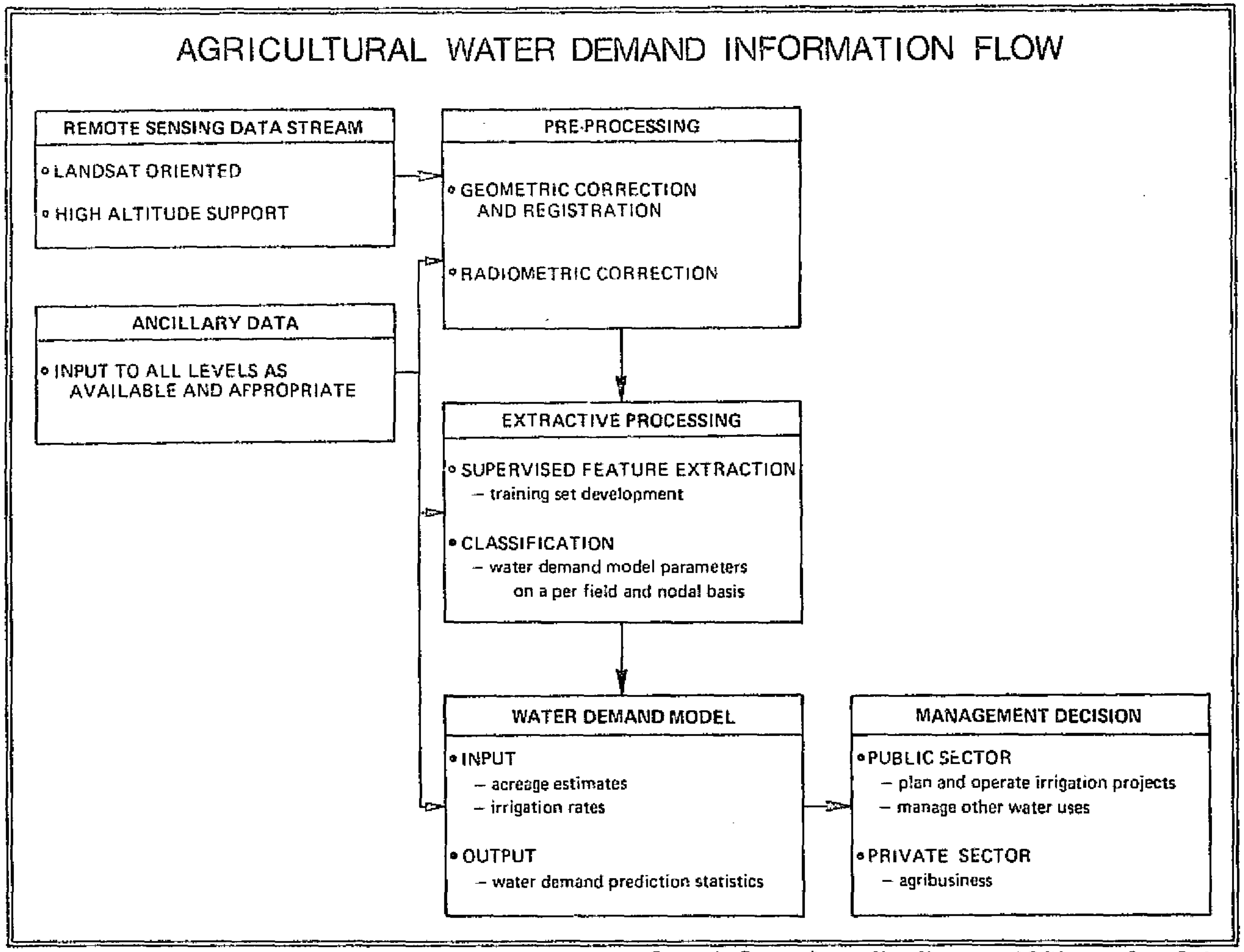

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Figure 3-2. A diagrammatic representation of data flow through a remote sensing water demand prediction system. Once User information requirements are defined and operational procedures developed for satisfying those requirements, the remote sensing data stream is processed (pre-processing and extractive processing) in conjunction with ancillary data to provide acreage and irrigation rate estimates. These basic inputs into the water demand prediction essentially drive the model. Water demand predictions are then used in both the public and private management decision sectors.

3.20 WATER DEMAND PREDICTION

3.21 Analytical Analysis and Ranking of Water Demand Variables

3.22 Introduction

The total Kern County hydrologic system is both complex and dynamic. The KCWA groundbasin model must therefore incorporate detailed, yet relatively stable geologic information, in conjunction with constantly changing agricultural land use information. The most dynamic element of this system is the amount of irrigation water applied to agricultural lands. This water may either be pumped from local groundwater basins, with a negative impact on groundwater levels, or imported from other regions, thus potentially having a positive impact on local groundwater levels. At present, approximately 1,150,000 acre-feet of water is imported yearly through state and federal projects. However, since the exact amount of groundwater pumpage and irrigation water applied to the land is not known, accurate estimates for both of these quantities are required as model inputs. In areas where complete metering of groundwater pumpage is not available, as is common in Kern County, the total amount of applied water (i.e. demanded water) must be estimated by knowledge of irrigated acreages and water application rates. Figure 3-3 graphically illustrates those variables considered to be of most importance to agricultural water demand prediction in the Southern San Joaquin Valley area of California. In order to more accurately assess the impact of these factors as they influence a water demand prediction, studies by our group during this report period have focused on the individual effects of these variables.

There is a wide spectrum of techniques which can be utilized to generate water demand predictions, as illustrated in Figure 3-4. These vary primarily according to the generality of the two primary inputs, i.e. acreage and application rate estimates. For the specific variables studied during this report period the two most extreme levels of input generality have been used. These levels entail irrigated cropland acreages and countywide average application rates for the most general approach, and crop type acreage and application rates as the most specific approach. It should be pointed out that the optimization of operational procedures to be accomplished at a later date may result in some intermediate approach.

As discussed in the May 1975 Annual Report, the more general approach using cropland acreages and an empirically derived countywide average application rate (3.38 acre-feet/gross acre) consistantly resulted in overestimations of water demand for the Lost Hills Water Storage District of Kern County. District-wide prediction accuracies from 1971 to 1974 averaged only 62%. Because the errors associated with these predictions were systematic, accuracies could be substantially improved by applying appropriate estimation ratios (i.e. corrective constants) which are calculated to minimize the systematic prediction bias. The reported improvement in the mean prediction accuracy accomplished through the application of such procedures was 31%, bringing the average accuracy to

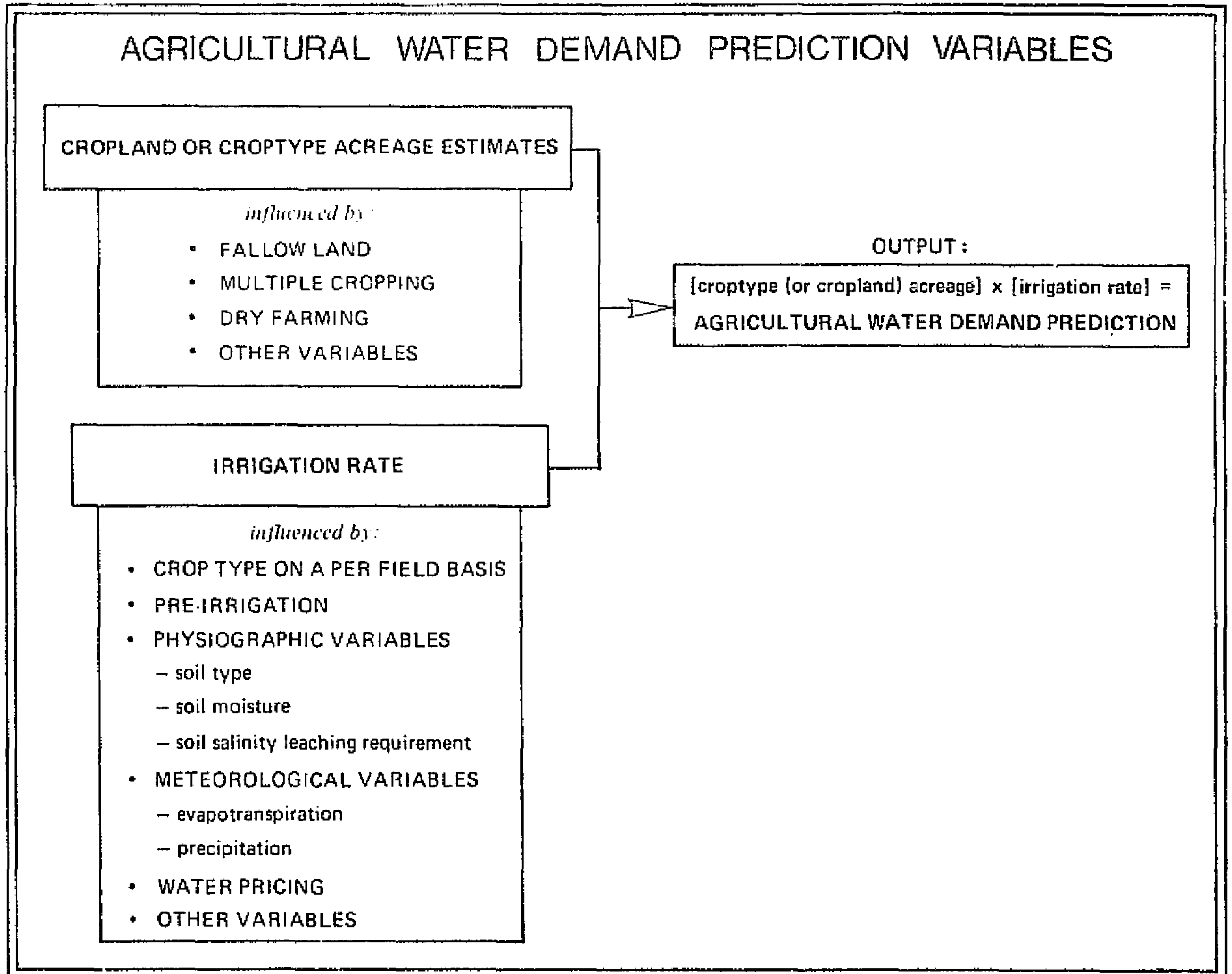

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Figure 3-3. The range of variables considered to be of greatest importance in determining agricultural water demand in the Southern San Joaquin Valley of California.

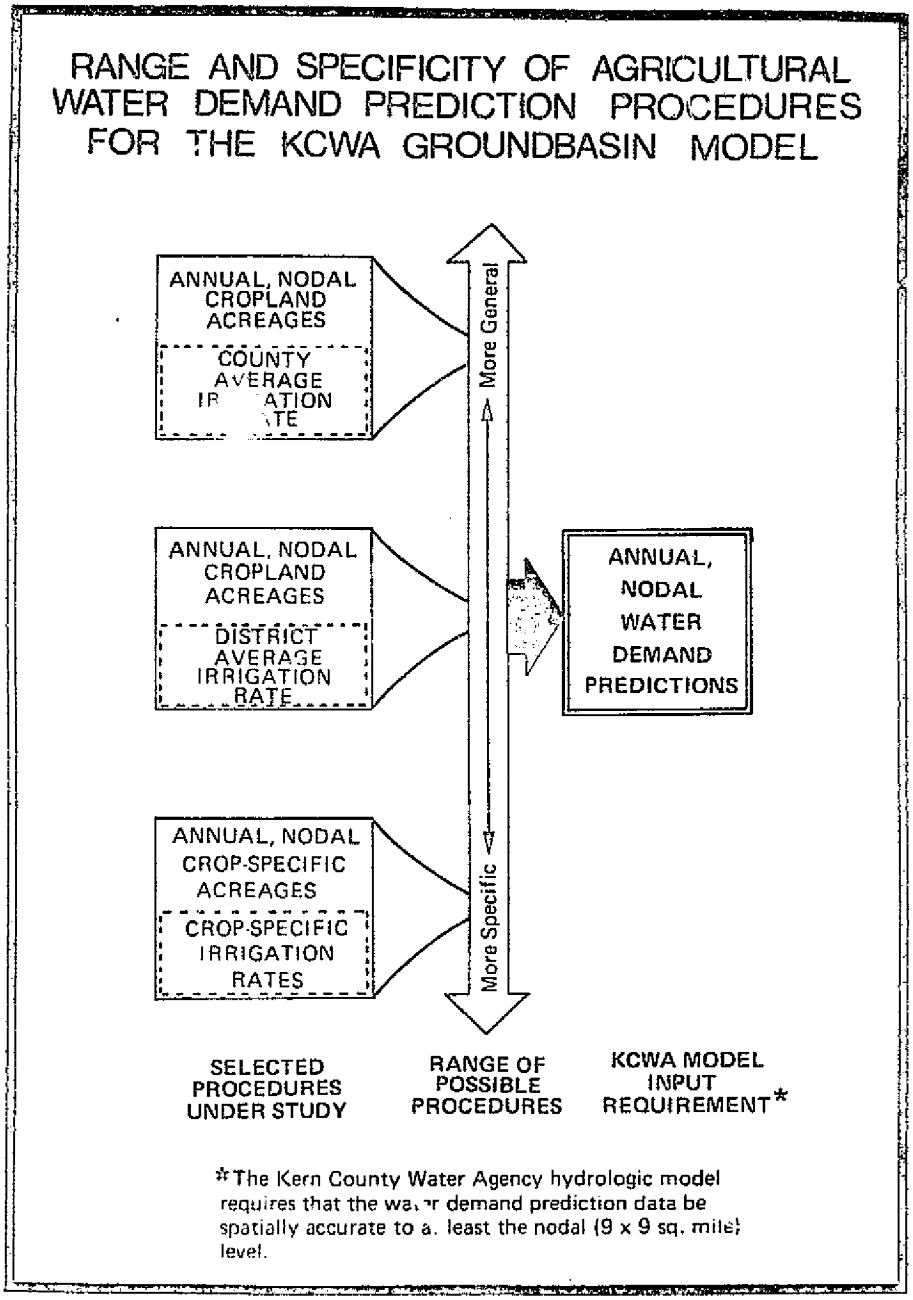

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Figure 3-4. The range of procedures from general to specific which may be employed to estimate nodal agricultural water demand in Kern County.

93%. The significance of this improvement is that <u>for the Lost Hills Water District calibrated cropland acreage estimates alone were capable of achieving sufficiently accurate water demand predictions for model input. However, as also reported, the calculation of reliable estimation ratios can only occur in areas where the total amount of applied water is known.</u> In Lost Hills there is a total reliance upon imported water, therefore these figures are available. However, in those areas where groundwater pumpage occurs, the total amount of applied water is an unknown quantity and sufficiently reliable adjustment factors cannot be calculated. Estimation ratios, then, improve prediction accuracy by accounting for the combined, yet consistent effect of various other factors influencing water demand, such as crop type, double cropping, fallow land, etc. With crop specific information incorporated into the Lost Hills predictions the average district-wide accuracies increased to 91%. Therefore in this case, it can be concluded that most of the prediction improvement value of the estimator ratio lay in its ability to account for crop specific information.

The purpose of our present research, reported herein, is the quantification and rank ordering of the individual variables involved in water demand prediction at the more specific nodal level. In addition to crop specific effects, the other variables studied to date include: fallow land, double-cropping, and pre-irrigation. These variables have been selected for study because of their anticipated importance and/or their amenability to study using remote sensing techniques. It is anticipated that water pricing policies and soil type effects will be analyzed during the next reporting period. As shown in Figure 3.3 all of these variables affect either the acreage estimate or the irrigation rates, the two basic inputs of the water demand prediction procedure.

Our previous studies have primarily involved the Lost Hills Water Storage District. We have recently shifted our emphasis to the Wheeler Ridge-Maricopa Water Storage District owing to the availability of more reliable collateral information. Both of these districts possess attributes which make them advantageous for study due to their complete dependency on imported water for irrigation, i.e. no groundwater pumpage is known to occur. The total amount of irrigation water used can thus be determined by examining California Aqueduct and canal records.

3.212 Goal

The objective of this research is the development of techniques to accurately predict total irrigation water demand and to determine its source. These techniques are being developed to operate on a nodal scale as required by the KCWA model. At present, the water prediction techniques are being developed using high altitude photography, LANDSAT imagery, and field survey crop maps. However, the project is oriented towards the development of cost-effective techniques using LANDSAT imagery. The development and refinement of water prediction techniques in the Lost Hills and Wheeler Ridge-Maricopa districts is continuing with the eventual

goal of applying these techniques to the remaining districts included in the hydrologic model area.

The immediate goal of this phase of the study is to quantify the effect of selected variables on the accuracy of nodal water demand predictions and to identify those remote sensing techniques and methodologies which will facilitate the inclusion of these variables in a water demand prediction procedure.

3.213 Methodology

Each variable i.e. crop type, fallow land, pre-irrigation, and double cropping, has been investigated individually to quantify the particular effect on the accuracy of its inclusion or exclusion in a water demand prediction procedure. For most variables, the effect on accuracy has been quantified for both of the two basic prediction methods, one using cropland data and the other utilizing crop type data.

The variations in accuracy due to the inclusion or exclusion of a variable in a specific water demand prediction using *crop type* data is quantified by comparing nodal crop type water demand predictions to the same predictions which have been improved through the consideration of the particular variable. For the purposes of comparison, the improved crop type prediction is assumed to be 100% correct. The difference in accuracy is calculated as the percent error of the prediction which did not consider the variable being investigated.

The difference in accuracy due to the inclusion or exclusion of a variable in a water demand prediction using *cropland* data is quantified in the following process: 1) The unimproved cropland prediction is compared to the improved croptype prediction. The latter prediction, as before, is assumed to be 100% correct. If the two predictions are compared the resulting improvement in accuracy is due not only to the inclusion of the variable in question, but also to the inclusion of crop type data. In order to separate the improvement due to inclusion of the variable from the improvement due to crop type data, it is necessary to make an additional comparison. 2) If an improved cropland prediction is compared to an improved crop type prediction, the resulting difference in accuracy is due to the inclusion of crop type data only. If this percent accuracy value is subtracted from the percent accuracy value resulting from the first comparison (unimproved cropland versus improved crop type prediction) the resulting difference is the change in accuracy caused by the inclusion of the variable in a cropland water demand prediction.

3.214 The Effect of Crop Type Information on Water Demand Prediction Accuracies

The crop pattern in a district or node is one of the most important factors for the accurate prediction of irrigation water demand. A node

TABLE 3-3

Selected 1974 Nodal Croptype Breakdowns and Resultant Nodal Average Irrigation Rates for the Wheeler Ridge-Maricopa Water Storage District

CROP GROUP OR TYPE	IRRIGATION RATE[1]	PERCENT OF TOTAL CROP ACREAGE				
		Node 195	Node 201	Node 206	Node 213 S	District
Alfalfa	4.4	5	0	0	0	2
Grain	1.1	30	0	3	36	5
Rice	7.0	0	0	0	0	0
Grapes	3.1	13	0	10	64	12
Dec. Fruit and Nut	3.2	0	0	1	0	8
Subtropical Fruit	3.0	0	0	4	0	6
Misc. Truck	3.0	6	0	42	0	14
Potatoes	2.7	17	0	1	0	4
Misc. Field Crops	3.0	0	0	1	0	1
Cotton	3.3	31	100	39	0	50
Sugar Beets	3.5	0	0	3	0	2
[1] AVERAGE 1974 IRRIGATION RATE BASED ON CROP ACREAGE AND CROP-SPECIFIC IRRIGATION RATES (ACRE-FEET/NET ACRE)		2.6	3.3	3.1	2.4	3.1

The above irrigation rates are taken from a document entitled: The Pacific Southwest Inter-Agency Committee Water Resources Council, Comprehensive Framework Study, California Region, Appendix X, p.99.

is most likely to have a particular water demand because of the pattern of crops in the nodes owing to the variability of crop-specific irrigation rates. The variation of crop-specific irrigation rates and the difference in crop patterns is shown for a select number of Wheeler Ridge-Maricopa Water Storage District nodes in Table 3-3. The average nodal irrigation rates are also shown. During this reporting period, the increase in accuracy with the inclusion of nodal crop type data in a water demand prediction procedure has been defined. Predictions generated from two procedures, one utilizing crop type data on a nodal basis and one using just cropland (i.e. agriculture/nonagriculture) have been compared in order to quantify the increase in accuracy due to the inclusion of crop type data in the water demand prediction. Predictions have been made for each of the 40 nodes in the Wheeler Ridge-Maricopa Water Storage District for the years 1972, 1973, and 1974. In the procedure using only cropland data the acreage in each node is multiplied by the appropriate annual district average irrigation rate. As a procedural note, it is important to realize that in this cropland prediction, the most accurate average irrigation rates are used; i.e. district average irrigation rates calculated for the specific year in which they are used. On a current operational basis less accurate irrigation rates would generally be used, such as a countywide irrigation rate, or an irrigation rate calculated for one year and applied to succeeding years. Water demand predictions made with such a cropland irrigation rate would be less accurate than predictions made with the annual, district rates used in this study.

The water demand prediction procedure utilizing crop type data requires the multiplication of the crop type acreage by each crop's specific irrigation rate. The resulting crop-specific water demand predictions are then totaled to produce the total irrigation water demand prediction. For the purpose of comparison, the latter predictions have been assumed to be 100% correct. Table 3-4 illustrates that the inclusion of crop-type data significantly increases the district-wide mean nodal water demand prediction accuracies by 6.3% for the three years studied; much larger impacts are possible and have been noted in the Lost Hills District.

TABLE 3-4

The Increase in Nodal Water Demand Prediction Accuracy with the Inclusion of Croptype (versus Cropland) Data for the Wheeler Ridge-Maricopa Water Storage District (1972-1974)

Node	1972	1973	1974	
	%	%	%	
195	3.8	8.2	19.9	
201	5.5	11.9	7.8	
206	6.1	3.2	1.0	
213 S	14.8	3.5	33.1	
⋮	⋮	⋮	⋮	
District wide mean nodal increase in accuracy (weighed by acre-feet)	8.4	5.9	4.5	$\overline{X}$ = 6.3%

An increase in water demand prediction of this magnitude can be illustrated by analyzing the difference between the 1974 district average irrigation rate and the average nodal irrigation rate (based on crop acreage and crop specific irrigation rates) for just four of the forty nodes in the water storage district (Figure 3-5). As illustrated, over or under-estimation of district water demand may result if only the cropland (agriculture/non-agriculture) data and the district-wide average irrigation rate are applied. District water demand predictions based on nodal crop type and crop specific irrigation rates are significantly more accurate.

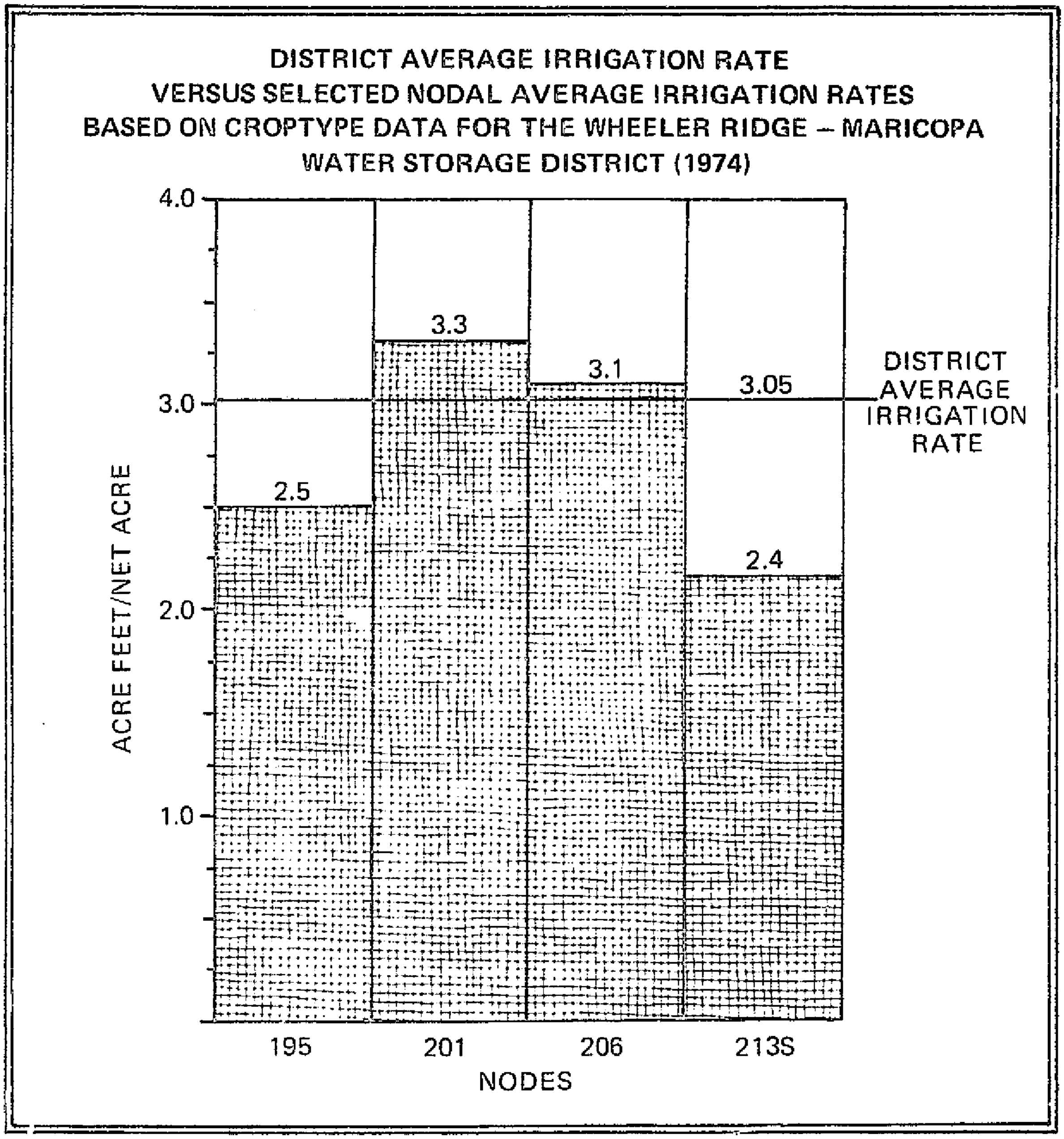
3.215 The Effect of Fallow Land Information on Water Demand Prediction Accuracies

Fallow land is tilled, but not cropped or irrigated. In many cropland mapping procedures, it is often included in the cropland category. In a water demand prediction procedure using cropland data, the inclusion of fallow acreage in the cropland (irrigated) acreage estimates will result in an overestimation of crop acreage, and therefore an overestimation of water demand. Conversely, fallow lands will not cause a decrease in accuracy in a water demand prediction procedure utilizing crop type acreage data because, if it is possible to discern the crop type in a field, it is also possible to classify fallow land. In a water demand procedure using crop type data, fallow fields would be identified and deleted.

This analysis will identify the effect of fallow land inclusion in a prediction which uses cropland acreages measured in the spring of the year; in other words it is a spring prediction. The amount of acreage which is fallow in the spring is greater than that which is fallow throughout the year, due to summer and fall planting. Therefore, the effect quantified here is larger than that which would be encountered with a prediction using multitemporal acreage data, where summer and fall plantings would be included.

In order to quantify the variation in accuracy resulting from the inclusion of fallow data, two comparisons have been made. One is the comparison of the unimproved cropland prediction, with a croptype prediction including fallow information. The other is a comparison of an unimproved croptype prediction and the improved croptype prediction (with fallow data). The differences of the resulting percent accuracy values is the improvement in accuracy with the inclusion of fallow data.

The change in cropland water demand prediction accuracies with and without fallow data have been computed for the Wheeler Ridge-Maricopa Water Storage District for the years 1972-1974. The increase in water demand prediction accuracy for four select nodes is shown in Table 3-5. The mean nodal increase in percent accuracy for all 40 nodes for the three year time period is 7.9%.



Geography Remote Sensing Unit, University of California at Santa Barbara

Figure 3-5. Comparison of district average irrigation rate and nodal average irrigation rates based on croptype data. Over or underestimation of district water demand may result if only the cropland (cropland/noncropland) data and the district-wide average irrigation rate are applied. District water demand predictions based on nodal croptype and crop specific irrigation rates would be more accurate.

TABLE 3-5

Increase in Percent Accuracy Due to the Inclusion of Fallow Data in a Nodal Water Demand Prediction Using Either Cropland or *Croptype* Information: Wheeler Ridge-Maricopa Water Storage District (1972-1974)

Node	1972		1973		1974	
198	5.0%	*(2.2%)*	2.8%	*(.9%)*	2.3%	*(6.8%)*
204	2.6	*(10.9)*	3.4	*(1.1)*	2.3	*(8.0)*
208	0.4	*(8.9)*	19.7	*(24.6)*	27.0	*(21.3)*
213	5.8	*(15.7)*	0.0	*(0.0)*	18.0	*(5.5)*
⋮	⋮		⋮		⋮	
District wide mean nodal increase in accuracy (weighted by acre-feet)	8.6	*(9.2)*	3.9	*(4.1)*	11.3	*(10.3)*
			$\overline{X}$ = 7.9% *(7.9%)*			

Similarily, by comparing unimproved and improved (including fallow data) crop type water demand prediction accuracies, it was found that the inclusion of fallow land data also increased district-wide mean nodal water demand accuracies by 7.9% over the three year period (Table 3-5).

In both the cropland and croptype investigations the changes in accuracy vary significantly from node to node as well as from year to year. This reflects the uneven occurrence of fallowing on a nodal basis which is affected by such diverse variables as the cropping pattern and rotational practices followed within given nodes, soil conditions, and economic variables such as the cost of water, the value of the potential crop, and the amount the land is taxed.

3.216 The Effect of Pre-Irrigation Information on Water Demand Prediction Accuracies

Pre-irrigation is the preliminary application of water to new cropland, primarily to increase the soil moisture to a sufficient level for the first planting.* In a water demand prediction procedure, pre-irrigation is important because it is an application of water in addition to the usual requirement. Pre-irrigation will have some effect on prediction accuracies even in nodes which have no area for further growth owing to the potential need to pre-irrigate lands which had been fallow. However, as more nodes reach their maximum potential cropland acreage the importance of pre-irrigation to water demand prediction accuracies should diminish. As a result of our research we feel at this time, consideration of this variable can prevent significant underestimation of water demand in those nodes where a considerable amount of land may be fallowed or in areas where large amounts of marginal land are being developed for agriculture. This is the case in the Wheeler Ridge-Maricopa Water Storage District where approximately 13,000 and 8,000 acres came into production during 1973 and 1974, respectively.

*In some instances the term also is applied to pre-irrigated fallow land.

Acreages included in the pre-irrigated category are those which came into production between successive cropping years beginning with the spring of the year. The majority of the lands (over 90%) which came into production are pre-irrigated due to the aridity of the area and the subsequent dryness of the virgin soil. Crops which do not always require pre-irrigation are grains and some of the shallow-rooted truck crops. Consideration of these crops, however, is included in the calculation of the average pre-irrigation rates. This enhances the credibility of the assumption that new lands which come into agricultural production are pre-irrigated.

The effect of the inclusion of pre-irrigation data on nodal predictions made with cropland data has been calculated for the Wheeler Ridge-Maricopa District for the years 1973 and 1974. Water demand due to pre-irrigation has been estimated by multiplying the pre-irrigated acreage by an annual Kern County average pre-irrigation rate. This value, calculated by averaging crop-specific pre-irrigation rates weighted by the respective county crop-specific acreages, is 0.7 acre-feet per acre for 1973 and 1974. The increases in accuracy with the inclusion of pre-irrigation data are shown for select nodes in Table 3-6. The average district nodal increase in percent accuracy for these two years was 2.8%.

TABLE 3-6

Increase in Percent Accuracy Due to the Inclusion of Pre-Irrigation Data in a Water Demand Prediction Using Either Cropland or *Croptype* Information: Wheeler Ridge-Maricopa Water Storage District (1973-74)

Node	1973	1974
192	0.0% *(0.0%)*	2.4% *(1.3%)*
195	.7 *(0.8)*	1.2 *(0.7)*
205	1.8 *(2.4)*	1.3 *(4.2)*
212	5.8 *(8.4)*	9.3 *(13.1)*
⋮	⋮	⋮
District wide mean nodal increase in accuracy (weighted by acre-feet)	3.0% *(4.1%)*	2.6% *(2.5%)*
	$\overline{X}$ = 2.8% *(3.3%)*	

The effect of the inclusion of pre-irrigation data on nodal water demand predictions made with croptype data has been determined by comparing a croptype prediction without pre-irrigation information with a croptype prediction with such data. Again, the latter is considered to be 100% correct for the purpose of comparison. The results are computed as the change in percent accuracy due to the inclusion of the pre-irrigation data. The average district nodal increase in percent accuracy for 1973 and 1974 is 3.3% (Table 3-6). In a number of nodes there was no new land and therefore, no increase in accuracy with the inclusion of pre-irrigation data. However, in other nodes there is a significant increase in accuracy with the inclusion of pre-irrigation data.

3.217 The Effect of Multiple-Cropping Information on Water Demand Prediction Accuracies

Multiple cropping is the presence in one field of two or more successive crops which complete all or most of their phenological cycle within one year. The occurrence of multiple cropping in an area effectively increases the cropped acres in an area by a factor of two or more, and thus, significantly increases the water demand of that area. In a water demand prediction procedure it is necessary to include data on multi-cropped areas in order to prevent underestimation of the water demand.

For most areas in Kern County, the multi-cropping pattern that will most often be encountered is double-cropping; triple-cropping is much less common. However, it is important to consider triple-cropping as its occurrence can effectively triple the water demand of an area. If the triple-cropped acres are concentrated within one node, significant errors of underestimation could occur.

The increase in water demand prediction accuracy due to the inclusion of multiple cropping information in a prediction made with cropland data was found to be 2.8% for 1974 (Table 3-7).

TABLE 3-7

Increase in Percent Accuracy Due to the Inclusion of Multiple-Cropping Data in a Water Demand Prediction Using Either Cropland or *Croptype* Information: Wheeler Ridge-Maricopa Water Storage District (1974)

Node	1974
210	2.0% *(0.0%)*
195	0.0 *(0.0)*
216	1.8 *(14.0)*
198	0.0 *(1.9)*
206	14.1 *(5.0)*
:	:
District wide mean nodal increase in accuracy (weighed by acre-feet)	2.8% *(3.6%)*

The effect of the inclusion of double-cropping data on nodal predictions made with crop type data has been calculated. The result was a district-wide mean nodal increase in percent accuracy of 3.6%. In both situations, the nodal increases in percent accuracy range from 1.0% to at least 20% for the entire district. This variation in percent accuracy improvement is due to the uneven nodal distribution of double-cropping. This distribution is largely the result of the nodal crop breakdown; double-cropping is possible only with certain crop types such as the grain

crops and certain truck crops, notably lettuce or potatoes. In nodes where concentrations of these crops occur such as node 206, there are likely to be significant amounts of double-cropping. In such areas a significant increase in water demand prediction accuracy can occur when double-cropping data is included in the prediction process.

3.218 Summary

The preceding research was initiated to identify, in a quantitative manner, the individual effects of several variables on water demand predictions. Analyses were completed on a nodal basis using both of the major data gathering techniques, i.e. cropland and croptype inventories. This research is proving useful for determining the specific information components necessary for accurate water demand predictions. From a ranked variable list, such as shown in Table 3-8, water resource managers may eventually be able to design an optimum data collection system for their respective regions by selecting those components most responsible for maximizing accuracy levels.

One of the most interesting effects noted in Table 3-8 is that produced by fallowing practices (8.0%) which exhibits a somewhat larger impact on water demand prediction accuracies than croptype data (6.3%). Since fallow land usually receives no irrigation, the rationale for its large impact is relatively simple; its exclusion will result in over-estimations equal to the otherwise assumed irrigation rate. Also of major importance are the errors attributable to the lack of croptype data, which will be equal to the difference between the assumed irrigation rate and the true crop specific irrigation rate (refer to Figure 3-5). Both fallow and croptype data were found to have two to three times the impact on water demand prediction accuracies when compared to multiple-cropping and pre-irrigation data . Of even greater importance is the larger range of potential nodal errors (nearly 5 times that of multiple-cropping and pre-irrigation) which are possible when croptype and fallow land data are not included in a prediction procedure. This supports the visual observation that both fallow and cropping patterns tend to occur in a more clustered manner than either double-cropping or pre-irrigation, resulting in significantly larger impacts on specific nodal accuracies.

It is important to rem ber that these variables are not necessarily independent, and any pre... ion procedure may incorporate one as a subset of another. For example, a thorough croptype inventory would be expected to include all four components, i.e. croptype, multiple-cropping, fallow and pre-irrigation data. The summary Table 3-8 thus documents only the individual impacts associated with each data component and suggests what types of data should be obtained.

To demonstrate the utility of remote sensing techniques to acquire data for water demand prediction, Node 199 (9 square miles in area) of the Wheeler Ridge-Maricopa Water District was selected and LANDSAT based water demand pre-

dictions compared to California Aqueduct canal records. Multidate LANDSAT imagery was analyzed to determine crop specific acreages for this node's 1973 growing season. The procedure employed in this prediction is discussed in detail in Section 3.23. Results of this water demand prediction for node 199 are shown in Table 3-9 which includes a comparison with conventional field based estimates and the more general estimates made from cropland data. In both the croptype and croplands predictions, LANDSAT derived estimates proved more accurate than conventional field based estimates. We should, however, view these initial results with some caution owing to the limited extent of the study area (5,760 acres). We are, however, encouraged and can suggest what appear as two primary reasons for improved accuracies via LANDSAT. First, better acreage estimates seem reasonable since even the LANDSAT derived cropland water demand prediction is more accurate than the water district's field based estimate. Secondly, as will be discussed in Section 3.5, the LANDSAT crop specific classification statistically infers that the field based crop map, rather than the LANDSAT derived classifications, may be incorrect in several instances. This conclusion is also supported by the slightly better water demand prediction obtained from the LANDSAT imagery.

TABLE 3-8

Summary Ranking of Water Demand Prediction Variables Investigated to Date and Their Influence on Nodal Water Demand Predictions in the Wheeler Ridge-Maricopa Water Storage District

Rank	Variable	Prediction Procedure	District-Wide Mean Nodal Increase in Water Demand Prediction Accuracy Due to Inclusion of the Variable	Range of Nodal Errors (%)
1	Fallow Land	Cropland Croptype	7.9 8.0	0-75 0-98
2	Croptype	Cropland vs. Croptype	6.3	0-90
3	Multiple-Cropping	Cropland Croptype	2.8 3.6	0-19 0-16
4	Pre-Irrigation	Cropland Croptype	2.8 3.3	0-20 0-29

Table 3-9. Water Demand Prediction for node 199 of Wheeler Ridge-Maricopa Water District, 1973

Water Demand Prediction Methodology		Prediction Accuracy	Water Demand Prediction	(Acreage) Water Demand			
				Barley[4]	Cotton[5]	Melons[6]	Sugarbeets[7]
CROPTYPE	Water District[1]	97.9%	10,643	(540) 594	(2320) 7262	(340) 972	(545) 1815
	GRSU[2]	99.3%	10,502	(304) 334	(2415) 7559	(330) 944	(500) 1665
CROPLAND[8]	Water District[1]	78.6%	12,658	(3745) 12,658			
	GRSU[3]	85.0%	11,996	(3549) 11,996			
California Aqueduct Canal Records (assumed 100% accurate)		100.0%	10,428				

[1]Water District field map

[2]LANDSAT based croptype classification and acreage estimates

[3]LANDSAT derived acreage estimate

[4,5,6,7]Crop specific irrigation rates:
Barley = 1.1 acre-ft/year
Cotton = 3.13 acre-ft/year
Melons = 2.86 acre-ft/year
Sugarbeets = 3.33 acre-ft/year

[8]A prediction based on the county-wide average irrigation rate of 3.38 acre-ft/year

3.22 REMOTELY SENSED CROPLAND INFORMATION FOR WATER DEMAND PREDICTION*

3.221 Introduction

The Geography Remote Sensing Unit in cooperation with KCWA, has recently completed an indepth analysis of the accuracy and cost- effectiveness of remote sensing techniques for acquiring cropland[1] data. Over 184,000 hec (456,000 acres), nearly one third of Kern County's agricultural lands (Figure 3-6), have been inventoried by: 1) terrestrial investigations conducted by cooperating water districts, 2) photointerpretation of high altitude color infrared photography, and 3) image interpretation of LANDSAT multispectral imagery. Analysis of the data generated by these inventories provided the basis for accuracy and cost-effectiveness comparisons. Cropland data collected in connection with this study is required as input to the groundbasin hydrology model of the San Joaquin Valley portion of Kern County.

Kern County Water Agency has county-wide jurisdiction for water resource management. KCWA is responsible for the forecasting of water supply and demand and is directly involved in the allocation and pricing of water to 16 cooperating water districts within the county. In recent years Kern County has experienced an increase in agricultural acreage due to the input of new water supplies from the California Water Project. This dynamic agricultural expansion prompted KCWA to contract for the development of a mathematical model of the water basin underlying the San Joaquin Valley portion of Kern County.[2]

Cropland Data Rationale - Before remote sensing techniques could be used to generate meaningful inputs to the water demand model, it was necessary to determine exactly what types of inputs were likely to be useful. These inputs are listed in Table 3-2. This analysis concluded that the most dynamic element of water movement into and through the Kern County groundwater basin occurs as a result of the application of irrigation water to agricultural lands.[3] In comparison to an average Southern San Joaquin

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* Jensen, J.R., Tinney, L.R., and Estes, J.E., "An Analysis of the Accuracy and Cost-Effectiveness of a Cropland Inventory Utilizing Remote Sensing Techniques," presented at the 10th International Symposium on Remote Sensing of Environment held at Ann Arbor, Michigan, Oct. 6-10, 1975.

1 The term "cropland" as used herein is synonomous with "irrigated acreage" as in the arid environment of Kern County it is estimated that 99% of the croplands present are actually irrigated.

2 This model was developed by TEMPO, Center for Advanced Studies, of Santa Barbara, California under contract to KCWA and the California Department of Water Resources.

3 Tinney, Larry R., et al, "Operational Use of Satellite and High Altitude Remote Sensing for Generation of Input for Water Demand Models," Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, April 1974.

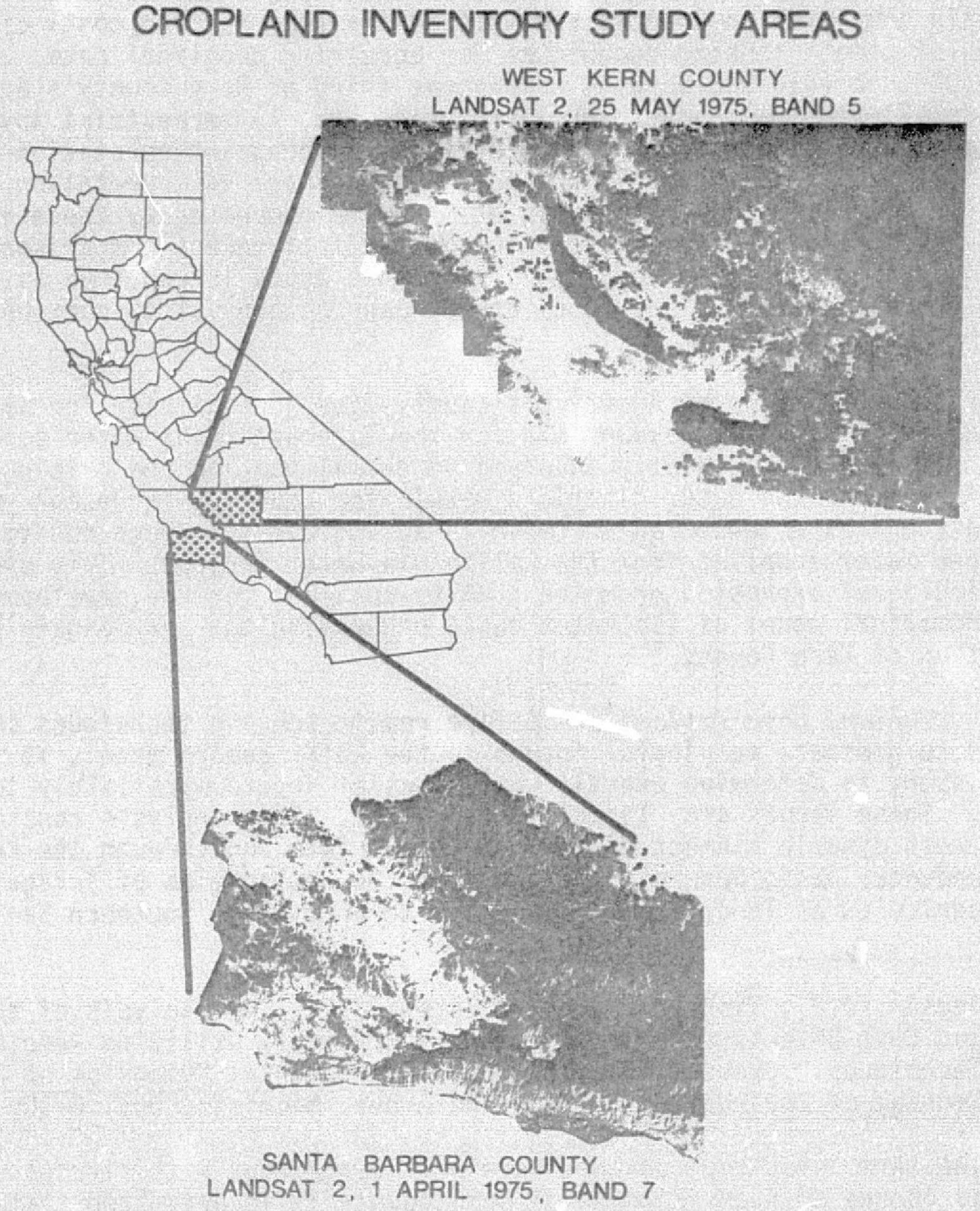

Figure 3-6. Cropland inventory study area in Kern and Santa Barbara Counties. Cropland mapping in Kern County from high altitude and LANDSAT imagery is documented in this section. The Santa Barbara study has just been initiated in cooperation with the Santa Barbara County Water Agency (see section 3.31 for discussion).

Valley precipitation rate of 7.6 to 12.7 cm (3 to 5 in) per year, the average yearly irrigation rate is 10,300 m^3/hec (3.38 acre-ft), or approximately 81.3 cm (32 in). Irrigation water may be pumped from the groundwater basin itself or imported from other regions of the state. Presently, approx mately 1.4 x 10^9 m^3 (12. x 10^6 acre-ft) of water is imported yearly while future contractural agreements call for 2.0 x 10^9 m^3 (1.7 x 10^6 acre-ft) by 1990.

As discussed in the previous section, an estimate of the "modelwide" water flow resulting from irrigation activities can be generated from knowledge of the total irrigated acreage and the average application rate. If the KCWA model operated only at a general modelwide scale, effective use could be made of multistage sampling techniques combining ground sampling and remote sensing to estimate total irrigated acreage. However, the model does not operate at such a general level and, except for providing a method for monitoring general trends, such information is of little value. In fact, it is a model requirement that the spatial dimension of cropland data be retained to at least the nodal level of aggregation, i.e. sampling has to be intensive enough to assure high spatial accuracies. While most sampling techniques are impractical under this restriction, many mapping approaches, such as those explored by the GRSU, have been found both accurate and cost-effective. To test the potential of remote sensing for providing cropland information as a model input, research was directed towards a comparison of several methodologies which employed remotely sensed data and conventional ground survey techniques. This research documented both relative and absolute accuracy as well as the cost-effectiveness of inventorying cropland by:

1. Conventional terrestrial methods
2. Color infrared high altitude (1:125,000) photography
3. LANDSAT (1:1,000,000; band 5) imagery

Field verified information employed in the assessment of interpretation accuracies was compiled by personnel of the Lost Hills (31,036 hec), Semitropic (90,649 hec), and Wheeler Ridge-Maricopa (62,847 hec) water districts located in Kern County. District personnel determined the 1974 crop year condition of fields (cropland and noncropland) by direct field examination. These data, although recognized as having their own variance, served as a control against which the remote sensing methodologies were tested for accuracy.

3.222 General Remote Sensing Cropland Inventory Techniques

Color Infrared High Altitude (1:125,000) Photographic Inventory - To assure a uniform scale in the high altitude cropland inventory, interpreted data were transferred to an acetate copy of a photogrammetrically controlled 1:125,000 basemap (see Figure 3-7). These maps include all nodal and section boundaries in the valley portion of Kern County. As the nominal 1:125,000 high altitude image scale corresponded with the 1:125,000 basemap scale, the visual transfer of cropland detail was accomplished with relative

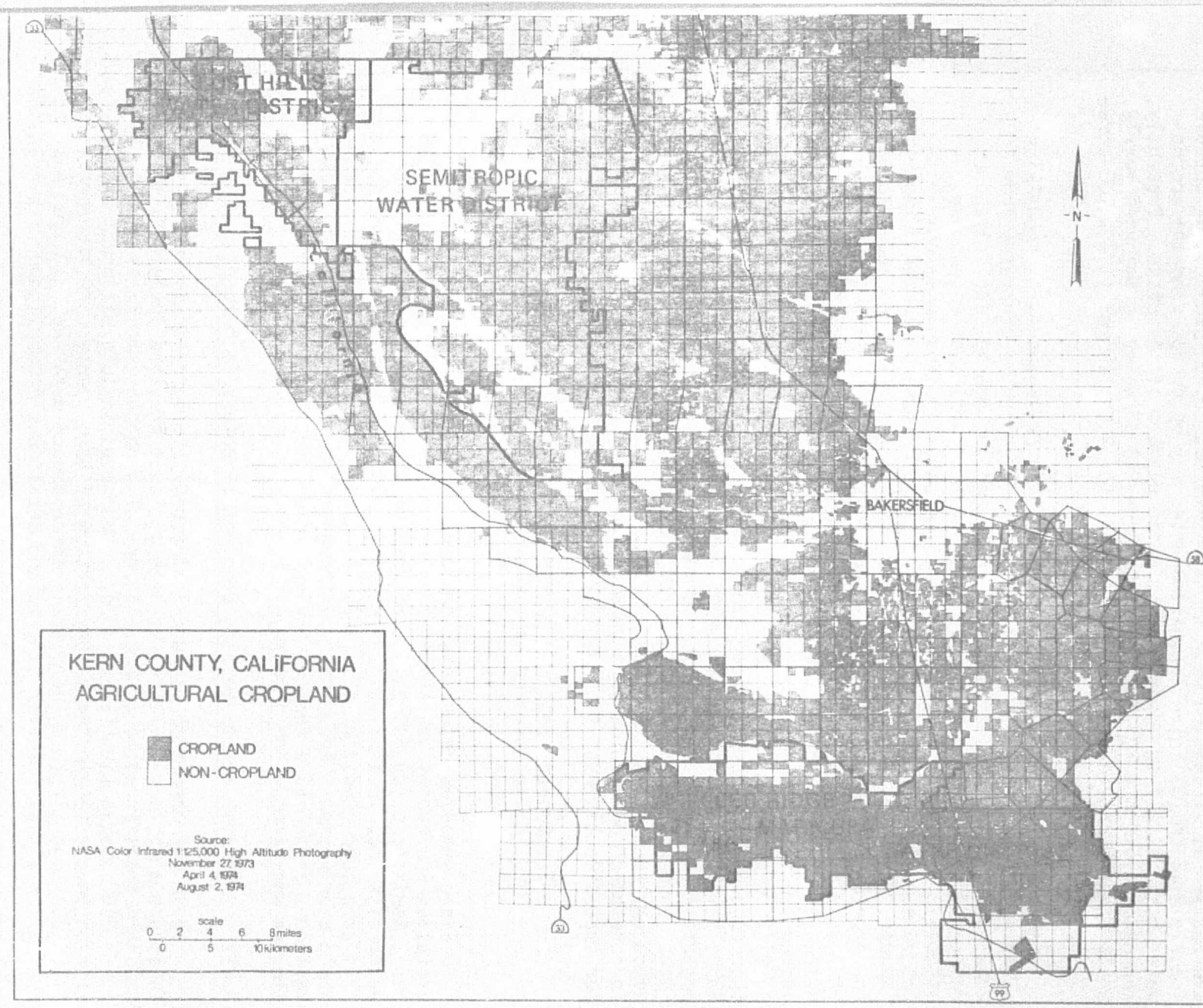

Figure 3-7. High altitude 1:125,000 scale cropland inventory of Kern County, California. Note the three water storage districts delineated which comprised the study area for accuracy and cost-effectiveness comparisons between conventional and remote sensing cropland inventory techniques.

ease and without ancillary equipment. The majority of field boundaries and roads follow section lines; however, when a variation between photo and map occurred, such as that introduced by geometric distortions away from the nadir, the photograph (or map) was adjusted on a section by section basis. Realignment was usually necessary only at the township level when the major portion of the area under investigation was in the central portion of the photography. Three dates, November 27, 1973, April 4, 1974, and August 2, 1974, were used to compile cropland data with the high altitude procedure.

As anticipated, the primary object recognition feature for identifying cropland is the magenta signature expressed by healthy vegetation. The optimum date for utilizing high altitude photography for cropland inventories in Kern County was found to be August (the approximate height of the growing season). A minor problem which exists with respect to the application of single date high altitude photography is the misclassification of abandoned fields, which are often difficult to differentiate from fallow fields. In addition, uniform grasslands completely enclosed by cropland are at times misinterpreted as irrigated crops.

LANDSAT (1:1,000,000; Band 5) Inventory - A number of the interpretive problems encountered when utilizing high altitude photography are minimized when using multidate LANDSAT imagery. Acquiring multidate imagery of a specific study area is simplified because LANDSAT imagery could be made available at 9 or 18 day intervals for much of the earth's cropland. Atmospheric conditions permitting, user agencies can now acquire sufficient imagery throughout the year to conduct a cropland inventory. As later discussed, an increase in the number of inventoried dates was found to substantially increase accuracies, thus giving LANDSAT-type imagery a distinct operational advantage over high altitude surveys. The synoptic view and greater geographic coverage (100 x 96.3 nautical miles) per frame is a further benefit as a greater amount of land can be inventoried on a single frame, resulting in a smaller expenditure for imagery.

In each LANDSAT inventory, an optical transferring instrument was used to simultaneously view a LANDSAT image and the 1:125,000 basemap. Interpreted information was then transferred directly onto the basemap in its correct planimetric position. The photographic enlargement of LANDSAT imagery to basemap scale, coupled with the high altitude overlay mapping procedure, should give results similar to the optical transferring method.

3.323 Approaches to Evaluating the Cropland Inventory Techniques

Initial Interpretation - To determine the variables which affect cropland inventory accuracies, an interpreter was instructed to inventory cropland in the Lost Hills Water Storage District (31,036 hec). This was accomplished in two modes. First, the interpreter inventoried three single dates of high altitude photography and the three single dates of LANDSAT images to determine the relative and absolute accuracies of each against

the field verified district inventory. Secondly, the interpreter utilized all three images at one time, thus producing a multidate high altitude (and LANDSAT) composite cropland inventory map. In this manner it was possible to determine if the single or cumulative multidate approach was more conducive to accurate inventories.

Results of this initial investigation are displayed in Table 3-10 There was no appreciable difference between single date high altitude or LANDSAT cropland inventories. Thus, although there is some variance between the single date high altitude and LANDSAT inventory accuracies, it is minimal, if not random. The results of the cumulative multidate inventory, Table 3-11, indicate that an increase in absolute LANDSAT accuracy (approximately 5%) is possible when this technique is utilized. Note that the absolute accuracy attained through the use of high altitude photography remained relatively unchanged. This suggests that the cumulative impact of LANDSAT single date images is greater than that of high altitude photographs when used for cropland inventories (for three dates). Interpreters attribute this to the more distinctive cropland signature (dark) present on LANDSAT band 5 images.

Based upon an analysis of interpretation errors made in both the high altitude and LANDSAT inventories, it was determined that most errors occurred in marginal cropland areas where many fields once in production had been abandoned. It was therefore considered possible to increase accuracies by using a simple dichotomous classification procedure in which a field is labeled "cropland" only if a crop is distinctly visible.

Dichotomous Interpretation - An additional interpretation was initiated which incorporated the modification discussed above. An interpreter was instructed to classify land as cropland only when a certain crop was present. The study area was enlarged to include Semitropic and Wheeler Ridge-Maricopa Water Districts, bringing the total to 184,534 hec, which is approximately one third of Kern County's agricultural cropland. In this experiment, the high altitude inventory once again utilized all three dates at one time to generate the cumulative cropland map. Figure 3-7 displays the map format of the high altitude cropland inventory as it was delivered to KCWA.

As the interpretation of three dates of high altitude photography had already been found comparable in accuracy to three dates of LANDSAT imagery in the previous analysis, an attempt was made to take advantage of both the greater cumulative impact and availability of LANDSAT imagery by incorporating five dates into the analysis (November 4, 1973; February 2, 1974; April 15, 1974; May 3, 1974; and August 2, 1974). The addition of two dates to the LANDSAT inventory was possible because of the 18 day overflight cycle, presently an operational advantage of LANDSAT when compared to high altitude photographic missions. Thus, the LANDSAT inventory was given an existent advantage that would most likely be incorporated into any operational cropland inventory procedure. It should be noted that under present operational constraints, an inventory would be very fortunate to acquire even three dates of high altitude photography.

TABLE 3-10 MEAN RELATIVE AND ABSOLUTE CROPLAND ACCURACIES
FOR THREE SINGLE DATE INVENTORIES OF THE LOST HILLS WATER STORAGE DISTRICT

High Altitude (1:125,000) Inventory					
	Ground Inventory	Interpreted Cropland	Noncropland	$\bar{X}$ Absolute Accuracy	$\bar{X}$ Relative Accuracy
Cropland	20,438	19,802 (96.9)*	636 [3.1]	(96.9)	(94.0)
Noncropland	10,598	1,860 [17.5]+	8,738 (82.4)	(82.4)	(88.9)
Total	31,036	21,662	9,374	28,540 (92.0)	(92.1)#

LANDSAT (1:1,000,000; Band 5) Inventory					
	Ground Inventory	Interpreted Cropland	Noncropland	$\bar{X}$ Absolute Accuracy	$\bar{X}$ Relative Accuracy
Cropland	20,438	19,809 (96.9)	629 [3.1]	(96.9)	(90.8)
Noncropland	10,598	2,503 [23.6]	8,095 (76.4)	(76.4)	(82.3)
Total	31,036	22,312	8,724	27,904 (89.9)	(88.4)

* (accuracy)
\+ [% error]
\# area weighted

TABLE 3-11 MEAN RELATIVE AND ABSOLUTE CROPLAND ACCURACIES
FOR A CUMULATIVE MULTIDATE INVENTORY OF THE LOST HILLS WATER STORAGE DISTRICT

High Altitud[illegible]25,000) Inventory					
	Ground Inventory	Int[illegible]ted Cropland	Noncropland	$\bar{X}$ Absolute Accuracy	$\bar{X}$ Relative Accuracy
Cropland	20,438	19,763 (96.7)	675 [3.3]	(96.7)	(95.4)
Noncropland	10,598	1,611 [15.2]	8,987 (84.8)	(84.8)	(91.2)
Total	31,036	21,374	9,662	28,750 (92.6)	(94.1)

LANDSAT (1:1,000,000; Band 5) Inventory					
	Ground Inventory	Interpreted Cropland	Noncropland	$\bar{X}$ Absolute Accuracy	$\bar{X}$ Relative Accuracy
Cropland	20,438	19,774 (96.7)	664 [3.2]	(96.7)	(99.2)
Noncropland	10,598	826 [7.8]	9,772 (92.2)	(92.2)	(98.5)
Total	31,036	20,600	10,436	29,546 (95.2)	(98.9)

For the LANDSAT interpretation, a separate overlay was created for each date of imagery. A cumulative composite LANDSAT cropland map was then generated and compared to the field verified district inventory. The results of this enlarged, dichotomous investigation are summarized in Table 3-12. For the 184,534 hec (456,000 acres) in the three water districts studies, the high altitude cropland inventory had mean relative and absolute errors of 0.3% and 2.9% respectively. The mean relative error for LANDSAT cropland inventories was found to be less than 1%, while the mean absolute error was 2%. This is significant because even though the scale has been decreased and resolution degraded when compared to 1:125,000 photography, the LANDSAT technique is capable of achieving a comparable, and in this case study even slightly higher, absolute accuracy, i.e. 98% versus 97%. This is attributed to the multitemporal characteristic of LANDSAT and its ability to provide adequate resolution for many dates throughout a growing season.

3.324 Cost Analysis

Personnel of the Lost Hills, Semitropic, and Wheeler Ridge-Maricopa Water Districts were cooperative in conducting the cropland ground surveys which facilitated the accuracy assessments. Equally important, however, are the estimated costs accrued by the districts for acquiring this cropland data (Table 3-13). The total estimated cost for conducting this 184,534 hec (456,000 acres) inventory of all three districts was approximately $3,000 and required six weeks to complete. At this rate, the cost for inventorying each 4,050 hec (10,000 acres) of cropland is approximately $66. The California Department of Water Resources (DWR) has estimated that a cropland survey of Kern County could be undertaken for approximately $5,000. The cost would be approximately $2,850 for DWR to inventory the 184,534 hec in the three water districts under investigation. The DWR cropland inventory cost, utilizing minimal hand-held oblique color aerial photography and extensive ground truth is therefore estimated to be $62.55 per 4,050 hectares.

The cost of acquiring cropland data by color infrared high altitude photography is cost-effective when compared to conventional terrestrial methods. By referring to Table 3-13 it can be seen that for each 4,050 hec inventoried, the cost is $2.98. The $136 it cost to acquire remotely sensed cropland data for the three districts represents only 4.5% of the $3,000 incurred by the Water Storage Districts' inventory. Time required to complete this three district analysis was minimal, only 8 hours. However, despite the high accuracies and cost-effectiveness of inventorying cropland with high altitude photography, it must be kept in mind that this analysis does not take into consideration the cost of aircraft mobilization, a necessary consideration for single purpose surveys. Table 3-13 also itemizes the costs associated with inventorying the three districts via LANDSAT imagery, approximately $90, or $1.97 per 4,050 hec. The relative lower cost of the LANDSAT inventory is due to the lower image acquisition costs.

TABLE 3-12 MEAN RELATIVE AND ABSOLUTE CROPLAND ACCURACIES FOR A CUMULATIVE MULTIDATE INVENTORY OF THE LOST HILLS, SEMITROPIC, AND WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICTS

High Altitude (1:125,000) Inventory					
	Ground Inventory	Interpreted Cropland	Interpreted Noncropland	$\bar{X}$ Absolute Accuracy	$\bar{X}$ Relative Accuracy
Cropland	116,833	114,031 (97.6)*	2,802 [2.4]	(97.6)	(99.7)
Noncropland	67,701	2,467 [3.7]+	65,233 (96.3)	(96.3)	(99.5)
Total	184,534	116,498	68,035	179,264 (97.1)	(99.7)#

LANDSAT (1:1,000,000; Band 5) Inventory					
	Ground Inventory	Interpreted Cropland	Interpreted Noncropland	$\bar{X}$ Absolute Accuracy	$\bar{X}$ Relative Accuracy
Cropland	116,833	114,781 (98.2)	2,052 [1.7]	(98.2)	(99.7)
Noncropland	67,701	1,771 [2.6]	65,930 (97.4)	(97.4)	(99.6)
Total	184,534	116,552	67,982	180,711 (98.0)	(99.7)

* (% accuracy)
\+ [% error]
\# area weighted

TABLE 3-13 COST-EFFECTIVENESS OF TERRESTRIAL VERSUS REMOTE SENSING TECHNIQUES FOR A CUMULATIVE MULTIDATE INVENTORY OF THE LOST HILLS, SEMITROPIC, AND WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICTS

Cropland Mapping Agency (Technique)	Cost for Inventorying all 3 Districts	Total Hectares in all 3 Districts	Total Cropland Hectares Inventoried	Time Required to Inventory all 3 Districts
		Cost for each 4,050 hec (10,000 acres)		
Lost Hills, Semitropic, and Wheeler Ridge-Maricopa Water Storage Districts (Terrestrial)	$3,000	184,534 ($ 66.00)	116,833 ($104.00)	240 hrs.
Department of Water Resources (Low Altitude Photography and Terrestrial)	$2,850[a]	184,534 ($ 62.55)	116,833 ($ 98.80)	230 hrs.
Geography Remote Sensing Unit (High Altitude 1:125,000 Photography)	$ 136[b] (includes $96 imagery cost)	184,534 ($ 2.98)	116,833 ($ 4.70)	8 hrs.
Geography Remote Sensing Unit (LANDSAT 1:1,000,000; Band 5)	$ 90 (includes $15 imagery cost)	184,534 ($ 1.97)	116,833 ($ 3.12)	15 hrs.

[a] This is a revision of the cost estimate presented in Chapter 3 of "An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques," May 1975, a NASA funded study by Colwell et al. The present cost estimate is based on the percentage of the county's cropland contained within the three districts, rather than the percentage of potentially irrigable land. This more accurately reflects true operational costs as a large amount of potentially irrigable land in the county is without irrigation water and does not require inventory effort.

[b] This includes the cost of imagery reproduction by NASA, but does not include the cost of aircraft mobilization.

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3.225 Conclusions

In terms of overall mean absolute accuracy, the LANDSAT cumulative multidate (band 5) black-and-white analysis yielded slightly superior results (98% accuracy) when compared to the high altitude color infrared inventory ($\geq$ 97% accuracy). High altitude photographic inventories should be considered a viable alternative to conventional techniques whenever adequate coverage is available for a specific study area. The remote sensing cropland inventories documented are cost-effective. Compared to the \$62-66 cost per 4,050 hec for the DWR and Water District cropland inventories, the high altitude and LANDSAT inventories required only 3-5% of this amount, i.e. \$1.97 - 2.98 per 4,050 hec. The mean time for the DWR and Water District inventories was 235 hours while the remote sensing inventories required only 12 hours. This represents a 95% reduction in time when croplands are inventoried using high altitude or LANDSAT techniques. Cropland data generated by these techniques is now being regularly input into the KCWA hydrology model. Current research is documenting the utility and cost-effectiveness of remote sensing techniques, based primarily upon LANDSAT imagery, for providing specific crop type information as an additional model input to predict water demand.

3.226 Technique Transfer to KCWA

In October, 1975, the Kern County Water Agency proposed an arrangement with GRSU whereby a photointerpreter would be hired by KCWA on a part-time basis to provide quarterly cropland acreage statistics for input to the KCWA hydrologic model. This KCWA employee will be trained by GRSU to utilize the LANDSAT cropland inventory technique previously described Based on problems encountered as the technique is transferred to the agency, a cropland inventory "cookbook" is being prepared as a NASA document for the benefit of other user agencies.

3.227 Santa Barbara County Croptype Inventory

GRSU has recently entered a joint study with the Santa Barbara County Water Agency to inventory croptype information in the south coast region. Croptype data generated for this project can also be aggregated to irrigated agriculture/non-agriculture information. This more general information will serve as detailed ground truth for assessing the accuracy and applicability of remotely sensing cropland inventories in the more temperate Santa Barbara agricultural region. The detailed discussion of this study is found in section 3.31 of this chapter.

3.23 REMOTELY SENSED CROPTYPE INFORMATION FOR WATER DEMAND PREDICTIONS

3.231 Introduction

Cropland (i.e. cropland/non-cropland) mapping in Kern County allows only a first-order approximation of water demand. As shown in the discussion of variables affecting water demand predictions, significant improvements in accuracy can be expected when additional parameters such as croptype and fallow are included. It has also been noted that of the variables examined to date, most will be available from a thorough croptype inventory procedure. The results of a LANDSAT croptype inventory and water demand prediction have been discussed in section 3.218. This section will examine the specific remote sensing techniques employed in a croptype inventory and conclude with a discussion of the results obtained from such an inventory of Node 199 of the Wheeler Ridge-Maricopa Water District.

The need for croptype inventories has been demonstrated through both the research of the Geography Remote Sensing Unit on water demand parameters, and the Kern County Water Agency's data needs. KCWA personnel have specifically stated that the generation of accurate and timely crop maps should be a major goal of GRSU water demand research. Although KCWA cannot currently fund such surveys, croptype information is still considered an important input to the groundbasin model. The DWR estimated cost of $34,000 for these surveys[1] makes it highly unlikely that KCWA will undertake conventional crop surveys as an individual effort. With many agencies constituting potential users of crop information, however, KCWA personnel envision a cooperative effort in the near future. Preliminary discussions have already begun among some of these potential user agencies to define their specific information requirements. It will be important to consider the multiple uses of this type of information in our cost-benefit analysis of remote sensing techniques.

3.232 Goal

The major aim of this portion of our research is to develop a procedure capable of cost-effectively implementing remote sensing techniques to generate croptype data as input to the KCWA model. From the beginning of this work it was believed that the temporal nature of this task would require multi-date imagery, a task for which LANDSAT imagery is well suited.

The present cost associated with conventional county-wide crop mapping (e.g. DWR's estimate) makes such an endeavor prohibitive on a yearly basis, even though there is an acknowledged need for such information by many potential users. Efforts to initiate a multi-agency cooperative yearly crop mapping program, based upon conventional techniques and at their known costs, is

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[1] This estimate is for a field survey supported by extensive low altitude 35 mm oblique aerial photography.

demonstrative of the perceived need for this type of information. Accordingly, a secondary goal of our research is to document the informational requirements of these additional user agencies and, where appropriate, incorporate them into a crop identification methodology based upon remote sensing techniques.

3.233 Methodology

The validity of using multispectral and temporal analysis techniques for crop identification from LANDSAT-type imagery has been well documented. Multispectral analysis is based upon the premise that tonal differences typically exist between objects (in this case agricultural fields) within some portion of the electromagnetic spectrum. Optimum use of these differences as a means of identifying the objects depends upon the exploitation of many variables, of which the band width and spectral sensitivity of the remote sensing system are typically the most controllable.

Temporal analysis, as it pertains to crop identification, commonly involves the use of "crop calendar" type information such as that included in our 1974 Annual Report for the major crops in Kern County. With knowledge as to the types of crops present in a region and their respective phenological cycles, probabilistic statements can be generated as to the likelihood of a field appearing in a given condition on any certain date, or set of dates, and belonging to a given crop class. The extension of these analysis techniques into an operational procedure for a region as large as that encompassed by the KCWA model (approximately 900,000 acres), however, is a difficult task. This is especially true in this particular region where a large variety of crops are grown and the informational requirements of the KCWA hydrologic model demand data that is accurate at the nodal level. The procedures developed for the task of crop identification may be subdivided into three sections: multiple image correlation, data extraction, and classification.

Multiple image correlation: This results from the need to register in some manner the same point, or in our case the same field, on each of the images used in the multiband and/or multidate analyses. Most manual techniques for field identification typically involve the enlargement of 1:1,000,000 LANDSAT images to a more useable scale (approximately 1:100,000). However, photographic enlarging processes entail a decrease in resolution and a loss of information while optical projection enlargement limits the potential methods available for data extraction.

To alleviate this situation the GRSU has investigated techniques for operating at the original image scale of 1:1,000,000 utilizing both optical as well as video magnification. The task of identifying individual fields has been accomplished by producing field boundary maps for each node or group of nodes and then reducing each map to the exact scale of LANDSAT imagery. The inclusion of prominent features in the map, such as canals and highways, makes alignment of the reduced overlay upon the imagery a relatively simple task. The most important requirement for this approach

is that precision photographic facilities be available to insure correctly scaled reductions. Field boundary overlays provide a method for multiple image correlation with data then extracted on a per field basis from successive images. This technique was reported in detail in our May, 1975 Annual Report. Recent improvements to this field boundary procedure include the use of high contrast prints instead of continuous tone transparencies for the LANDSAT enlargements and a more operable mapping scale of 1:62,500. An optical transfer device is now used to more effectively transfer detailed field boundary information from the high altitude photography to an acetate overlay placed upon the LANDSAT enlargements.

The utility of a field boundary overlay reduced to LANDSAT scale would decrease if field boundaries were to markedly change. We have examined three representative agricultural regions in Kern County, each approximately 23,000 acres, to determine the magnitude and characteristics of field boundary changes. The results of this examination suggest updates every two to three years should suffice if interim maps indicating only the changed boundaries are used as an additional guide to data extraction.

Data Extraction: The Geography Remote Sensing Unit's ability to register and interrogate LANDSAT Computer Compatible Tapes (CCT's) has nearly reached operational status. However, hardware delays have necessitated the use of video (analog) densitometric extraction techniques. When CCT's can be utilized by our image processing system, the improvement in radiometric accuracy should result in improved classification accuracies. GRSU's video image analyzer is currently being integrated into the UCSB Computer System Laboratory's (CSL) Interactive Signal Processing System, thereby expanding our image processing capabilities. This digital image processing system will facilitate the use of various automated and semi-automated techniques for data extraction and analysis. This system has also been proposed as the basis for a remote terminal with access to the RSRP CALSCAN pattern recognition programs. The present need for this link, however, has been reduced by the UCSB Geography Department's implementation of Purdue University's LARSYS (version 3.0) pattern recognition programs.

Classification: The final stage of crop identification involves the analysis of field spectral signatures to determine whether individual crop types exhibit adequate uniqueness (and uniformity) to allow accurate classification. Class spectral plots and statistical analyses, e.g. a pairwise divergence analysis, allow the user to define an optimum subset of available channels to be used for classification. This reduction of data dimensionality is an important stage in any pattern recognition project due to the higher computational costs associated with highly dimensioned data. By using class training sets both the optimum combination of channels and expected classification accuracies can be estimated.

The actual decision rule used for classification is commonly either a linear or maximum likelihood discriminant function. For the crop identification example discussed in the following section a linear discrimirant was considered optimum as training set accuracies were 100%.

3.234 Crop Identification in Node 199 of Wheeler Ridge-Maricopa Water District

For an initial test of our remote sensing techniques for crop identification Node 199 of the Wheeler Ridge-Maricopa Water District has been selected. This node was selected because it provided a crop assemblage for which complete training data could be obtained from surrounding nodes, a criterion favorable to our present means of data extraction. As are most nodes in the KCWA model, node 199 is composed of 9 sq. miles or 5760 acres. A much larger region, such as the entire Wheeler Ridge-Maricopa Water District, might have been undertaken had a more automatic technique for data extraction been operable.

Training set data were obtained from LANDSAT imagery for the 1973 crop year. Twenty-eight (28) individual channels were examined. LANDSAT bands 5 and 7 (0.6 - 0.7 and 0.8 - 1.1 microns), in that order, were found most useful for discriminating between the four crops in this node, namely barley, cotton, melons, and sugarbeets. Examination of class spectral plots demonstrated complete discrimination between all class pairwise combinations by June 12, 1973 using only three channels of data, i.e. April 2, 1973 (band 7); April 20, 1973 (band 5); and June 12, 1973 (band 5). Using a linear discriminant analysis classifier and equal a priori probabilities, training set classification accuracies of 100% were obtained. The lowest assignment probability was .996 suggesting no need for the use of a maximum likelihood classifier (which does not assume equal covariances and hence generally achieves slightly higher accuracies than a linear discriminant).

When applied to test data from node 199, the training set accuracies were not maintained. The results of the node 199 classification are shown in Table 3-14. Although apparently not as accurate as expected, the LANDSAT based classification resulted in more accurate water demand predictions than the conventionally derived field predictions (refer back to Table 3-9). Of the fields incorrectly classified, the lowest class assigned probability was .914, suggesting the very real possibility that the LANDSAT classification may be more accurate than the field map. These results are graphically presented in Figure 3-8. This figure shows the training sets and node 199 test data occurring in four rather distinct clusters when plotted according to the first two canonical variables.

This remote sensing crop identification procedure can be employed by any user having access to simple densitometric equipment and a discriminant analysis classification algorithm. Further research will investigate the usefulness of other algorithms (including the maximum likelihood algorithm of LARSYS) for identifying crops in Kern County. Specific continuing research topics include the value of per-field versus pixel-by-pixel classification, and signature extensions, both temporally and spatially. The results of this research will have a significant impact upon the findings of our cost-benefit analysis of operational remote sensing programs for crop identification.

TABLE 3-14

Node 199 Classification Accuracy

Class (based on field map)	No. of Fields	% Correct	No. of Fields Classified by Discriminant Analysis* of LANDSAT Into: Barley	Cotton	Melons	Sugarbeets
Barley	9	44.4	4	0	1	4
Cotton	33	97.0	0	32	1	0
Melons	6	66.7	0	2	4	0
Sugarbeets	5	60.0	0	2	0	3
% Correct Classification Overall = 81.1						

* Linear discriminant analysis classification of LANDSAT imagery using 4/02/73-MSS 7, 4/20/73-MSS 5, and 6/12/73-MSS 5. Wheeler Ridge-Maricopa Water District 1973 crop map, obtained by conventional field techniques, was used as ground truth. Training set data was gathered from surrounding nodes; training set classification accuracy was 100%.

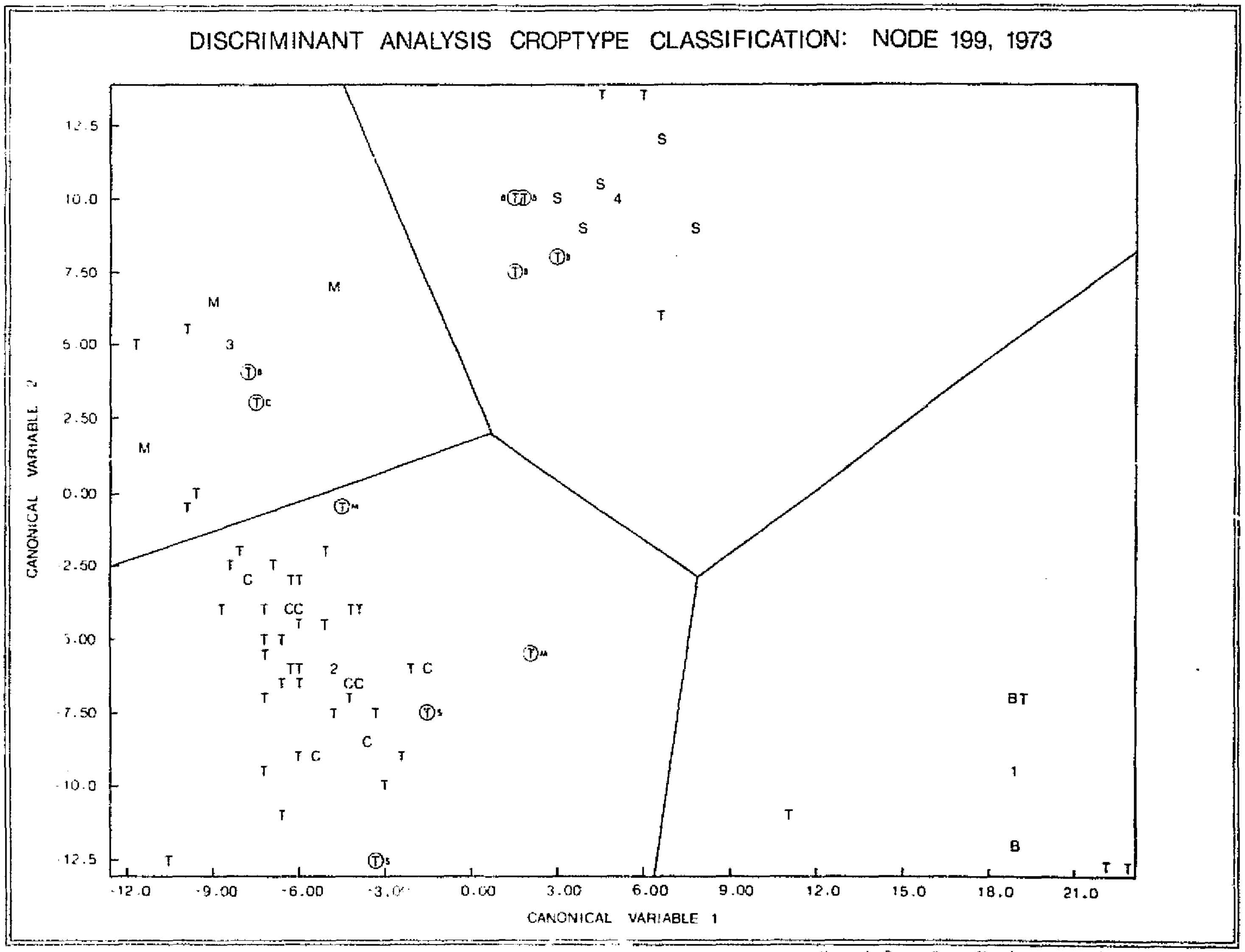

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Figure 3-8. LANDSAT based discriminant analysis crop classification of Node 199 (Wheeler Ridge-Maricopa Water District), 1973 growing season. Plotted are the first two canonical variables derived from 4/2/73-MSS 7, 4/20/73-MSS 5, and 6/12/73-MSS 5 imagery. Decision boundaries separate the four fairly distinct clusters, each representing a different crop-type. Training fields, from surrounding nodes are identified by letters B = barley, C = cotton, M = Melons, S = sugarbeets; class means are shown as 1, 2, 3, and 4 respectively. Test data (T) represents individual fields of Node 199. Fields misclassified are circled and correct classification, according to Water District crop map, are subscripted.

3.235 Crop Identification Application: Cotton

Another potential user of specific crop identification information is the Plant Protection Service of the Department of Agriculture in their program to control pink bollworms. Title 3 of the California Administrative Code, Section 3595, names Kern County as a member of Host-Free District 4, which requires that from December 15 through March 15 no cotton plants or parts thereof may be present "in a state or condition capable of sustaining or continuing pink bollworms in any state." U.S.D.A. currently generates each year a June 15 cotton distribution map by field investigation (approximate cost $8,000) for use in its summer moth trapping program. Any expansion of the current pink bollworm population will most likely also result in the necessity of a winter plowdown monitoring program. The GRSU intends to fully document the feasibility of LANDSAT remote sensing techniques for generating the information required for these programs. The first stage of this effort entails an analysis of the specific informational requirements of this application. These requirements are:

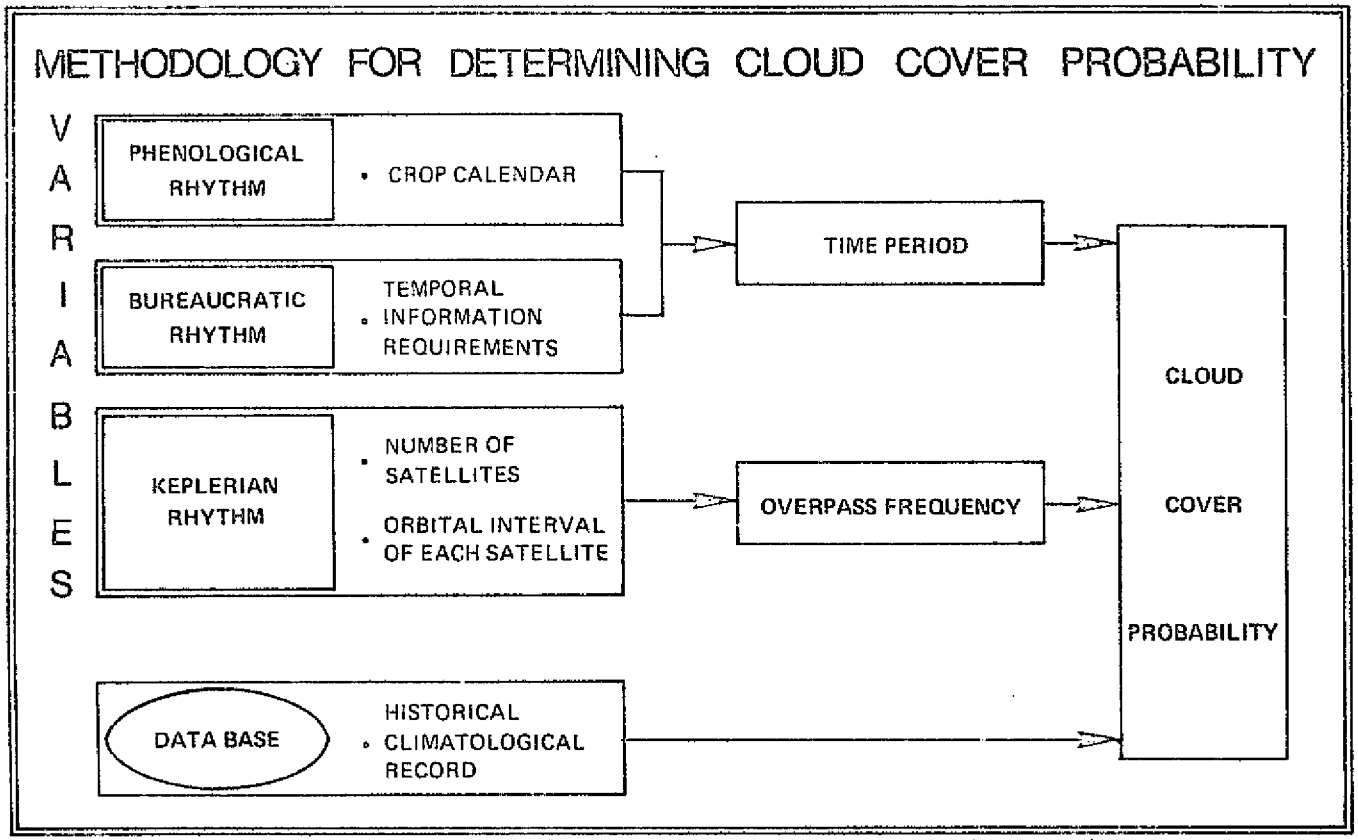
1. The knowledge of the cotton crop calendar for Kern County including:
   - ° planting (March 15 - April 20)
   - ° growing (April 20 - September 15)
   - ° harvesting (September 15 - December 15)
   - ° plowdown (December 15 - March 15
2. The spectral reflectance signatures of cotton on LANDSAT imagery during the appropriate period of cotton's phenological cycle.
3. The probability of having $\leq$ 20% cloud cover for the Kern County region.

This user agency application is one of several potential uses of crop identification data that remain to be investigated in order to provide a thorough cost-benefit analysis of our remote sensing techniques.

3.236 Cloud Cover Probability

The probability of obtaining usable, essentially cloud-free imagery for a given geographic area is one of the most important parameters to be considered when developing any operational remote sensing crop identification procedure. In particular, because cropland or croptype inventories in a water demand procedure require multiple dates of imagery to be effective, the probability of obtaining relatively cloud-free imagery is of critical importance.

The purpose of this research is to 1) identify the variables that affect the prediction of cloud cover probabilities, and 2) develop a probability forecasting technique whereby imagery obtained from a remote sensing system can be evaluated in terms of its utility for a given application.



Geography Remote Sensing Unit, University of California at Santa Barbara

Figure 3-9. This diagram illustrates the variables to be considered when determining the probability of a given cloud cover for a particular remote sensing application.

The three variables (Figure 3-9) used to determine probabilities for cloud cover in Kern County are:

- crop calendar (phenological rhythm)
- timeliness of information (bureaucratic rhythm)
- interval between orbits of one or more satellites (Kelprian rhythm)

Unlike the phenological, bureaucratic and Keplerian rhythms which can be accurately predicted and charted, cloud cover represents an unpredictable natural cycle. Past climatological records can be analyzed to determine probabilities for future weather patterns; however, these can be misleading. For example, because cloud cover is typically discontinuous it is difficult to generalize. Cloud cover observations made at Bakersfield (the only cloud cover data station in the study area) are normally used to characterize the cloud cover for the entire southern San Joaquin Valley study area. In addition, cloud cover is recorded in 10ths which tells nothing of its spatial distribution. Nevertheless, since these past records are the only data base available for cloud cover prediction they must be utilized.

A full 22 years of daily cloud cover has been used as the data base for the probabilities given in this report. For Kern County agricultural applications of LANDSAT imagery, cloud cover probability predictions were derived from the following data:

- 22 years of cloud cover data obtained from the National Weather Service, Bakersfield, California;
- 10a.m. cloud cover corresponding to the LANDSAT overpasses in Kern County;
- Percent of time that cloud cover was $\leq$ 20% (assuming $\geq$ 20% cloud cover would make the image unusable).

This data is then applied to the rhythms illustrated in Figure 3-9 by means of the following binominal equation:

$$P(x) = \frac{n!}{x!\,(n-x)!}\, p^x q^{n-x}$$

P = probability of obtaining usable $\leq$ 20% cloud cover imagery for a given application
x = number of usable images desired
n = number of overflights possible in given time period
p = % of time that usable image occurs, based on historical data
q = % of time that non-usable images occur, based on historical data

Therefore in order to transfer this methodology to another geographical area and/or application it is necessary to obtain the historical cloud cover data for the area, and then determine the phenological, bureaucratic, and Keplerian rhythms for each specific application.

Cloud Cover Considerations for Cropland and Cotton Inventories: In applying this methodology to a cropland inventory in Kern County, June 1 to September 30 was judged to be the optimum time period to acquire imagery. To study the utility of single versus multiple satellites, cloud cover probabilities were calculated for 1 to 3 satellites each on a different 18 day cycle as illustrated in Table 3-15. For the semi-arid San Joaquin Valley it is 99% probable that up to 3 usable dates of LANDSAT imagery will be available in any year between June 1 and September 30. This high probability is possible with just *one* satellite.

Cotton inventory and plowdown monitoring requires information between December 15 and June 14 to meet California State Department of food and Agriculture information needs. The results of a cloud cover probability study for this remote sensing application are also displayed in Table 3-15. Because imagery is required throughout much of the winter and spring (December 15 - June 14) of the year for this inventory, the probability of obtaining 1 to 3 usable dates is considerably lower. In this instance, the use of more satellites or more frequent overpasses would increase the probability of acquiring the $\leq$ 20% cloud cover information quite significantly.

TABLE

PROBABILITY OF OBTAINING USABLE SATELLITE IMAGERY*
FOR KERN COUNTY

CROPLAND INVENTORY	1 SATELLITE ON AN 18 DAY CYCLE			2 SATELLITES EACH ON A DIFFERENT 18 DAY CYCLE			3 SATELLITES EACH ON A DIFFERENT 18 DAY CYCLE		
	1 USABLE	2 USABLE	3 USABLE	1 USABLE	2 USABLE	3 USABLE	1 USABLE	2 USABLE	3 USABLE
June 1 - July 11	.9663	.7028	.1479	.9990	.9826	.8820	1.0000	.9986	.9913
July 12 - Aug. 20	.9759	.7357	.1145	.9995	.9883	.9030	1.0000	.9997	.9957
Aug. 21 - Sept. 30	.9809	.7733	.1778	.9996	.9925	.9317	1.0000	.9998	.9971
June 1 - July 31	.9946	.9267	.6349	1.0000	.9994	.9928	1.0000	1.0000	1.0000
Aug. 1 - Sept. 30	.9972	.9530	.7064	1.0000	.9998	.9971	1.0000	1.0000	1.0000
June 1 - Sept. 30	1.0000	.9996	.9954	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Aug. 1 - Aug. 31	.9341	.4939	+	.9992	.9534	.7064	.9999	.9976	.9731
COTTON INVENTORY AND PLOWDOWN MONITORING									
Dec. 15 - Jan 14	.3813	.0438	+	.6203	.1983	.0337	.7746	.3633	.0930
Jan. 15 - Feb. 14	.3813	.0438	+	.6203	.1983	.0337	.7746	.3633	.0930
Feb. 15 - Mar. 14	.5327	.0913	+	.7819	.3545	.0702	.9387	.7197	.3946
Mar. 15 - Apr. 14	.6125	.1355	+	.8553	.4832	.1424	.9497	.7476	.4184
Apr. 15 - May 14	.5000	.1750	+	.9000	.5750	.2000	.9687	.8122	.4809
May 15 - June 14	.7680	.2520	+	.9514	.7171	.3195	.9716	.9028	.6908

* Usable imagery includes 0-20% cloud cover

\+ Not applicable

3.24 REMOTE DETECTION OF PERCHED WATER AND SALINITY

3.241 Introduction

During this reporting period research has been conducted in the following areas:

- literature review and evaluation of soil and water processes responsible for the formation of perched water tables and saline conditions in Kern County;
- based on this analysis, remote sensing procedures are proposed which will identify and inventory these parameters;
- perched water and soil salinity ground truth data has been collected in order to determine the efficacy of the proposed remote sensing techniques.

As will be seen from the following discussion, perched water tables and excessive soil salinity are highly correlated in their spatial distribution, the former being largely responsible for the latter. Due to this relationship, what were previously separate investigations are now reported in an integrated manner.

3.242 Soil Factors Influencing the Creation of Perched Water Tables and Excessive Soil Salinity

3.2421 PERCHED WATER

> "If the profile above a water table consists of a sequence of layers such that a highly conductive one overlies one of low conductivity, then it is possible for the flow rate into the top layer to exceed the transmission rate through the lower layer. In such circumstances, the accumulation of water over the interlayer boundary can result, temporarily at least, in the development of a *perched* (or secondary) *water table*... ...if infiltration ceases, the perched water table will eventually tend to disappear by downward seepage into the primary water table." (Hillel, 1971)

The subject of this research is the various soil factors influencing the creation of shallow "perched" water tables, as defined above, and associated soil problems, especially salinization. Soil drainage, in general, will be examined but the focus will be perched water tables, specifically those present in Kern County, California.

3.24211 Soil Moisture

Large quantities of water are required to satisfy both the evapotranspiration requirements of plants and act as a solvent in the soil

solution, which is largely responsible for the transfer of soil nutrients to plants. Excessive soil moisture alone is not necessarily harmful to plants provided sufficient oxygen (required for plant respiration) is available and toxic substances are not present in excessive amounts. However, excess water can block soil pores and effectively retard aeration, resulting in oxygen deficiencies that can occur in conjunction with the relatively rapid accumulation of carbon dioxide to harmful levels.
The effects of poor soil drainage have historically had major impacts on man's agricultural activities. "Once thriving civilizations based on irrigated agriculture in river valleys (as in Mesopotamia, for instance) have been destroyed through the insidious, and for a time invisible, process of salt accumulation caused by poor drainage."[1] Though excessive soil salinity, such as that which occurs in a number of areas within Kern County, is one of the more dramatic effects associated with poor drainage, many others are possible and, indeed, widespread. As an example, it is common in many river valleys for excessive yet non-saline soil moisture to result in the soil becoming an unsuitable medium for plant growth. One characteristic of poor drainage is oxygen deficiencies (anaerobic conditions). It has been noted that:

> "Under anaerobic conditions, various substances are reduced from their normally oxidized states. Toxic concentrations of ferrous, sulfide, and manganous ions can develop. These, in combination with products of the anaerobic decomposition of organic matter (e.g. methane) can greatly inhibit plant growth. At the same time, nitrification is prevented, and various plant and root diseases (especially fungal) are more prevalent."[1]

It has also been suggested that the products of anerobic digestion by soil microorganisms may further encourage drainage problems by blocking soil pores to a greater amount than the more completely digested products of aerobic digestion.[2] Whenever the effective rooting zone is inhibited, plants may even be expected to suffer from a lack of nutrients. In addition, the "puddling" of clay soils and compaction in general are additional effects more likely to occur under excessive soil moisture conditions.

From this brief examination of potential conditions related to moisture in soils it can be seen that soil moisture exhibits a complex series of relationships with factors directly affecting agricultural activities, requiring careful monitoring in any total soils management program.

3.23212 Soil Drainage Factors

As we examine the factors influencing soil drainage at a more specific

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1 Hillel, Daniel, Soil and Water, 1971.

2 UNESCO, Physical Principles of Water Percolation and Seepage, by J. Baer et al, 1968.

level there are individual soil variables such as structure and texture, which control the movement of soil moisture. More generally, geomorphic variables affecting the processes of soil formation and their geographic distribution will be examined.

Initially it is important to define some soil water terminology in order to put the following discussion in its proper context. To begin with are the various soil water components:

- water vapor
- pellicular water
- hygroscopic water
- gravitational water
- water in solid state
- crystalline water
- chemically bound water

Among these, the first four are of most immediate interest to discussions concerning soil water movement. Definitions for these are:

1. "Water vapor" - completely fills gaps within the soil and shifts from regions of higher pressure to regions of lower pressure.

2. "Hygroscopic water" - is water that condenses at the surface of the particles. When dry soil gets in touch with humid air, soil particles absorb moisture, and the whole soil volume increases until some magnitude is reached, corresponding to the maximum hygroscopic effect. The maximum hygroscopy may have these values for various soils for sands about 1%; for silt - up to 7%; for clay - up to 17% of the total dry matter.

3. "Pellicular water" - is formed on particles under the influence of strong molecular forces of adhesion.

4. "Gravitational water" or groundwater - is free water not subject to the action of attraction forces towards the surface of the solid particles. This water moves under influence of gravity and is subject to hydrodynamic pressure.[1]

Natural soils consist of solid material, water and air; the water and air filling the pore spaces between the particles of solid matter. At least part of the soil pores, in most soils, contain some air as well as water, i.e. they are "unsaturated." When all pores are filled with water the soil is considered "saturated." "Porosity" may be defined as the volume of pores per unit total volume. Since the porosity for sandy soils, which readily transmit water, is about 0.35-0.45 compared to 0.40-0.60 for

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[1] Polubarinova-Kochina, P.Ya, Theory of Ground Water Movement, translated by Roger DeWiest, New Jersey: Princeton University Press, 1962.

typical clays and peat which do not readily transmit water, it can be seen that porosity does not necessarily control water movement.[1] "Effective porosity" may be defined as the pore volume which is effective with respect to flow, i.e. the partial volume of the porespace in which the water is free to move per unit total volume of the soil. As might be expected, the effective porosity of clay is much less than the absolute porosity, while in sands the two quantities are nearly equal. Of greater importance than either porosity, however, is the "pore size." This is due to the fact that total flow rate in soil pores is proportional to the fourth power of the radius; thus the flow through a 1mm pore is 10,000 times greater than that through a 0.1mm pore.

Three forces may be considered to generally control the movement of water through a given soil. They are:

- Matric forces
- Osmotic forces
- Gravity forces

The "matric" force is due to the attraction of soil solids for water via adhesion (pellicular water) or absorbtion (hygroscopic water). Capillary action occurs due to absorption and the surface tensions of water. "Osmotic" forces result from the attraction of ions and other solutes for water gravity forces is a self-evident term. The tendency for soil water to move is primarily related to the combined energy level effect of these forces, with the direction from higher energy levels to lower ones. Negative potentials are sometimes referred to as "suctions."

Two common measurements of water transmitting capability are:

- seepage
- permeability

The gravitational movement of water is called seepage, while permeability is a measure of the ease with which the flow occurs. The permeability of soils can vary so widely that its physical significance is often difficult to comprehend, and the velocities of seeping water are subject to even greater variations than permeability.[2] Table 3-16 details the seepage coefficients of several soil types illustrating this wide range of values.

[1] Verruijt, A., Theory of Groundwater Flow, London: Macmillan, 1970.

[2] Cedergren, H.R., Seepage, Drainage, and Flow Nets, New York, John Wiley & Sons, 1967.

TABLE 3-16. Average Values of Seepage for Various Soils[1]

Designation of soil	Average value of seepage in cm/sec.
Clean sand	0.01
Clayey sand	0.005
Sandy loam	0.003
Carbonated loam	0.00005
Clay	0.000005
Saline clay	0.0000003
Carbonated loess	0.0001
Noncarbonated loess	0.00001
Salt-marsh	0.0001
Peat	0.002

The ease with which water can travel through soils and rocks, or "hydrolic conductivity," largely depends on:

° Viscosity of the flowing fluid (water)
° Size and continuity of the pore spaces or joints through which the fluid flows, which in soils depends upon:
  - shape and size of the soil particles (texture)
  - density
  - detailed arrangement of the individual soil particles (structure)
° Presence of discontinuities

The "viscosity" of water is a measure of the ease with which the fluid layers are moving, or slipping in relation to each other. Specifically, it is the resistance or "drag" offered to motion. It decreases with higher temperatures and may vary approximately 100% over the wide range of temperatures encountered in arid environments (see Figure 3-10). However, it is usually considered beyond effective control.

The individual grain or particle size distribution of a soil, which determines its texture, significantly affects permeability. Permeability is very sensitive to the quantity, character, and distribution of the finest fractions, i.e. the clays and silts, due to their ability to block soil pores.[2] Typical permeabilities of soils and aggregates of several sizes are listed in Figure 3-11.

Particle arrangement, or soil structure, can influence permeability in two major ways.

° through sorting or stratification
° through particle orientation or grouping

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[1] Polubarinova-Kochina, op. cit.

[2] Cedergen, op. cit.

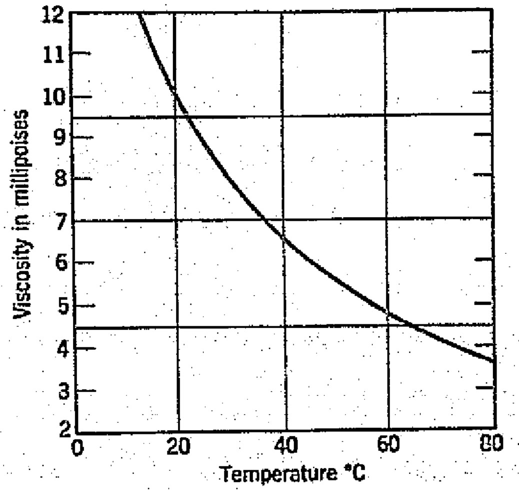

Figure 3-10. Viscosity of pure water as related to temperature (Cedergren, 1967).

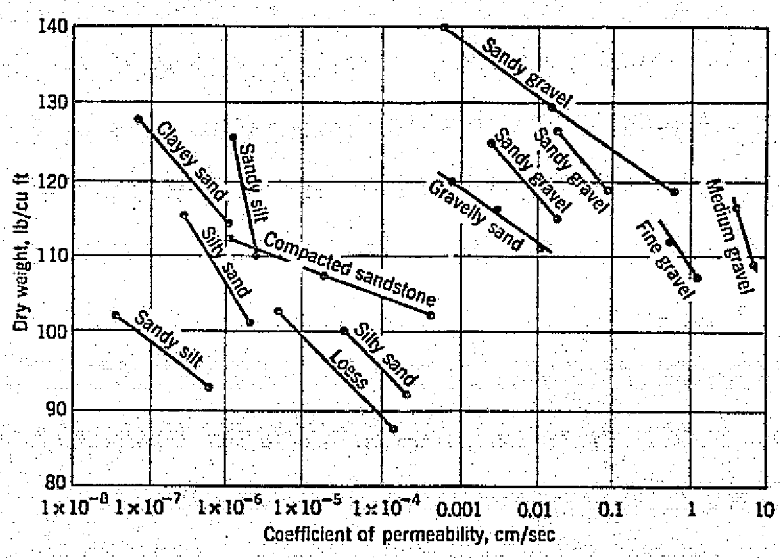

Figure 3-11. Relation between coefficient of permeability and soil type and density (log scale).

Soil deposits normally exhibit some degree of stratification when formed naturally. Of importance to the soil drainage problems in Kern County is the fact that water-deposited soils are normally composed of a series of horizontal layers more permeable in a horizontal than vertical direction. These deposits are often associated with soil drainage problems, especially since their deposition presupposes a relationship to water.

Though less important than soil structure and texture, the density, which is related to porosity, sometimes has a substantial influence on permeability. Any factor that tends to make a soil more dense, such as compaction, reduces permeability. Unless counterbalanced by structural improvements, the net impact of long-term agricultural activitivity as that which has occurred in several areas within Kern County, may be to increase soil drainage problems through compaction. Figure 3-12 generally typifies the decreases associated with soil consolidation and graphically illustrates the greater problems common to the finer textured soils (through both structural loss and an increase in soil densities, especially organic clays). This data supports the observation of permeability losses in clays when puddling occurs and the granular structure of the soil is 'oken down.

The effects of discontinuities such as physical breakdown or a crack in a soils structure are most evident in the finer textured soils, such as montmorillonitic clays, with high shrink/swell capacities. When these soils commonly crack during dry weather periods they initially allow rapid water movement, until the cracks swell shut again and movement is reduced to a minimum. Discontinuities in other soils are often related to the cracks and joints typical of specific soil structures.

3.24213 Groundwater Flow

The position of groundwater is mainly determined by the percolation rate of precipitation or irrigation water through the overlying unsaturated zone. In a reciprocal manner, the water table level affects the soil moisture profile and flow conditions above it. Movement of saturated water composing the groundwater is primarily governed by soil permeability and gravitationally induced gradients. Being saturated, no suction gradients or variations in wetness and conductivity normally occur. Water in unsaturated soil, in contrast, is strongly affected by suction gradients. Its movement is also subject to large variations in conductivity resulting from changes in soil moisture content.

Three general terms associated with groundwater flow are useful when discussing the formation of perched water tables such as those found in western Kern County:

<u>Aquifer</u>: a geologic formation or stratum containing water in its voids or pores that may be removed economically and used as a source of water supply. Unconsolidated alluvial deposits of sand

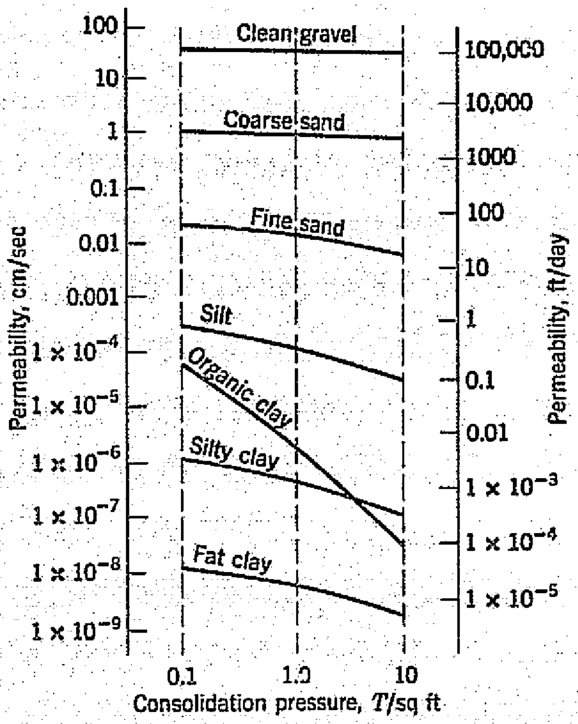

Figure 3-12. Permeability versus consolidation pressure.

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and gravel, consolidated sandstones are examples of water-bearing strata.

Aquiclude: a geologic formation so impervious that for all practical purposes it completely obstructs the flow of ground water (although it may be saturated with water itself), and completely confines other strata with which it alternates in deposition. A shale is an example.

Aquitard: a geologic formation of a rather impervious and semi-confining nature which transmits water at a very slow rate compared to the aquifer. Over a large area of contact, however, it may permit the passage of large amounts of water between adjacent aquifers which are separated from each other. Clay lenses inter-bedded with sands, if thin enough, may form aquitards.

Whenever aquitards or aquicludes have a slope component, groundwater will tend to migrate under the influence of gravity and accumulate in topographic lows, analogous to that of surface water flowage.

3.24214 Genesis of Perched Water Tables

With this brief examination of soil water movement complete, some attention may now be placed upon the more general factors associated with the formation of soils that tend to produce perched water conditions. The five basic factors of soil formation are climate, biologic activity, topography, time, and parent material. Though one could argue the specific merits of several required conditions, appropriate topography appears the dominant factor responsible for the formation of a perched water table with climate and parent material influential in controlling the severity of the situation. Man's agricultural activities, especially irrigation, could be thought of as a biotic factor that can rapidly multiply the severity of natural situations, especially in arid environments.

3.24215 Perched Water Tables in Kern County

An examination of the San Joaquin Valley floor portion of Kern County reveals the presence of a number of both physical and man induced conditions generally associated with perched water table formation. The economic impact of the development and expansion of areas affected by perching of water tables will be introduced later to emphasize the magnitude of this problem in terms of agricultural activities within Kern County.

The geology of the San Joaquin Valley floor portion of Kern County is shown in Figure 3-13, with cross-sections illustrated in Figure 3-14. The continental deposits of the West Side of Kern County occupy a broad structural trough between the Jurassic-Cretaceous (190 M,BP-65M, BP)* basement complex of the Sierra Nevada to the east and the folded and faulted

* The annotation M,BP indicated Million years Before Present.

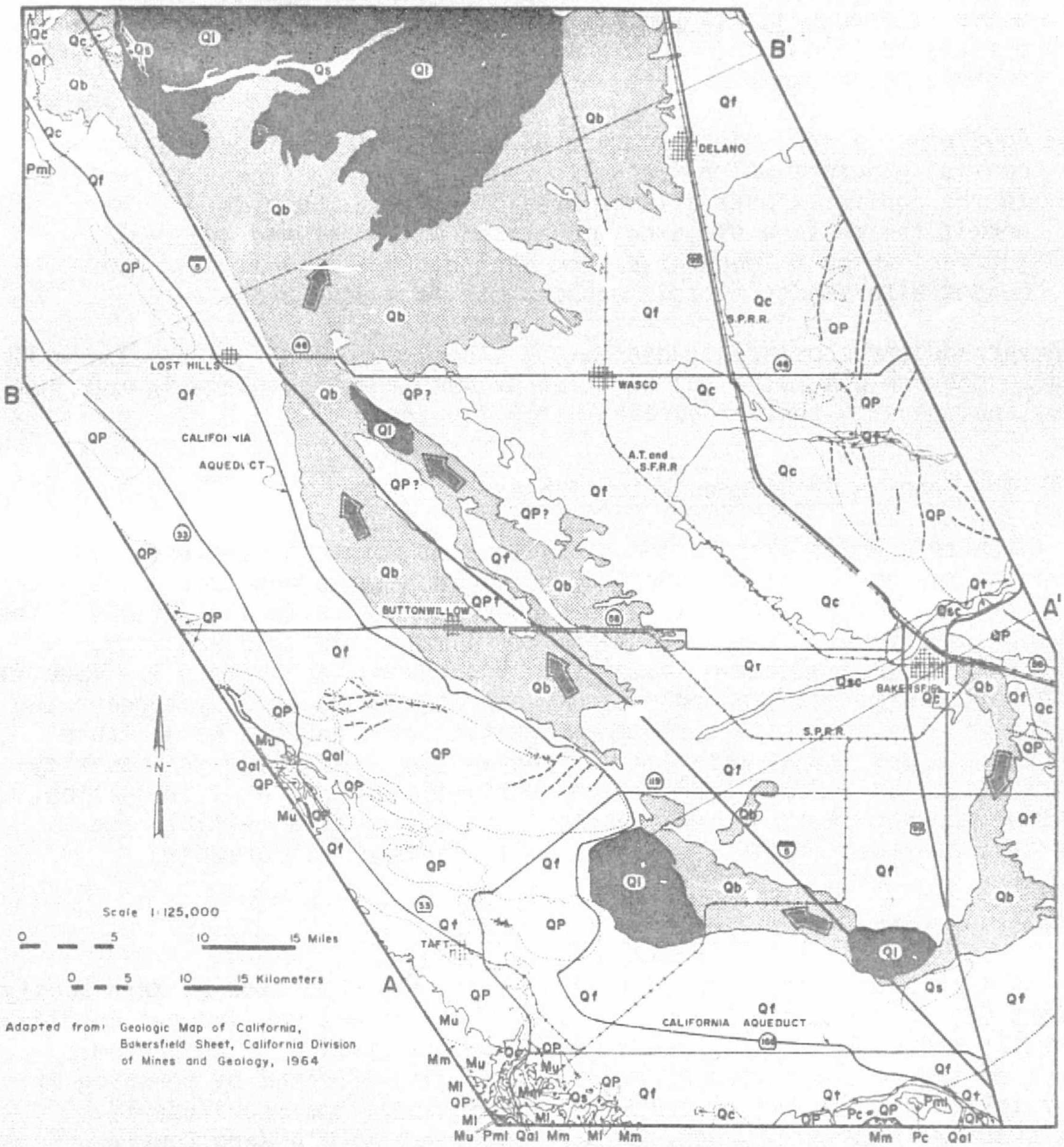
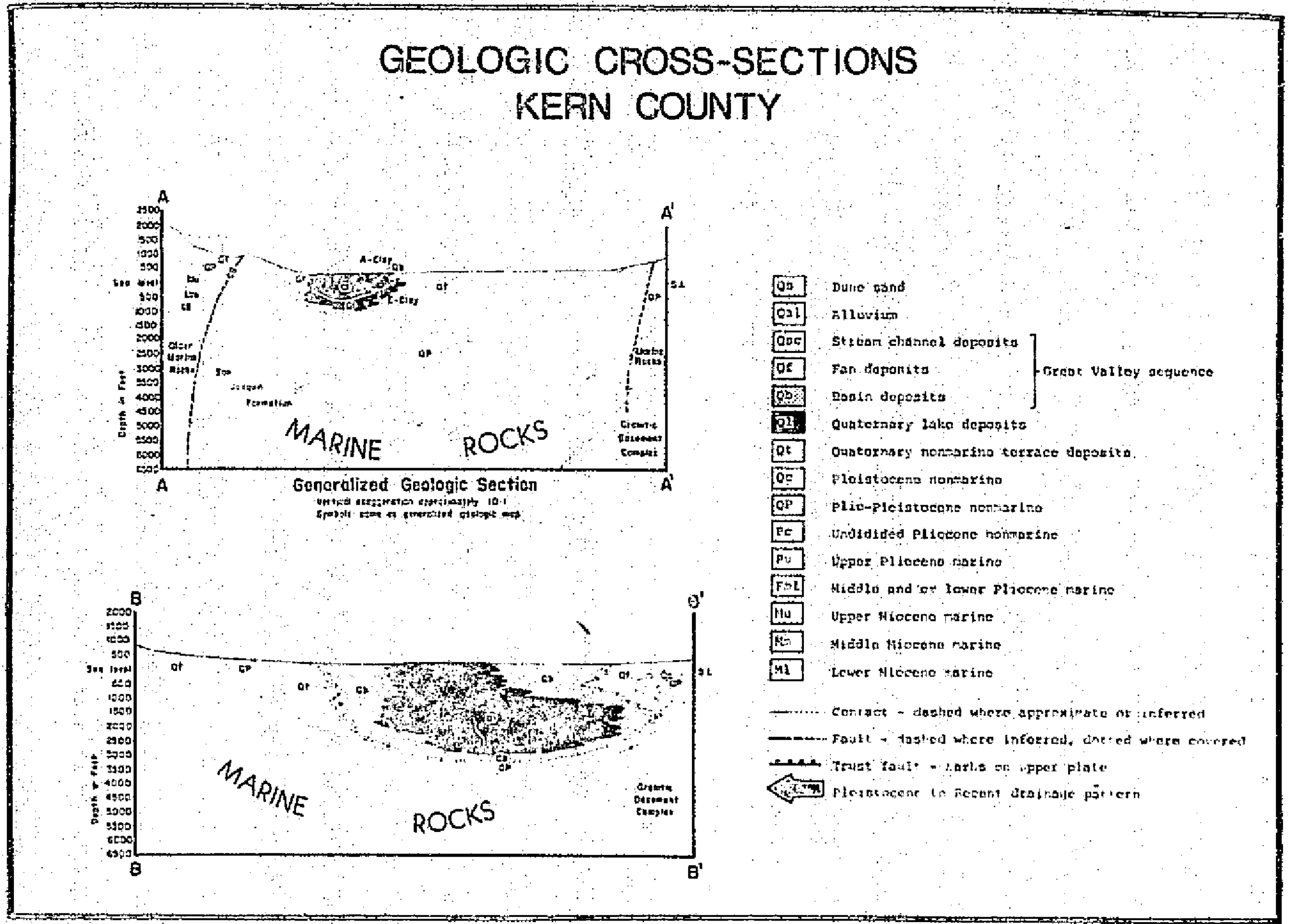


Figure 3-13. Generalized Geologic map of the Southern San Joaquin Valley. The legend is in Figure 3-14.



Geography Remote Sensing Unit, University of California at Santa Barbara

Figure 3-14. Kern County geologic cross-sections showing clay lenses formed by Quaternary lake deposits.

tertiary marine sediments of the Coast Ranges to the west. Continental deposits found in this region consist primarily of alluvial-fan and lucustrine (lake deposit) sediments which have been accumulating in the area since Miocene times (13M,BP).

Lithologically, the continental deposits vary from clay to boulder size. Differences in lithology are due to variation in parent material and/or the depositional environment. Parent material variation is a function of both textural and mineralogical differences of the individual grains. The Kern River and other Sierra Nevada sources (both present and past) are mainly responsible for the deposition of the course granitic sand, gravel, and boulder size rocks. The majority of the deposits are well weathered and rounded sand and gravel, which tends to make these layers porous and permeable. The sediments derived from the Coast Ranges consist of very fine sand to fine silt size material, which tends, as noted earlier, to exhibit high porosity but generally low permeability. Permeability is also a function of depositional environment. Alluvial-fan deposits typically consist of course grained silt to sand size materials (high permeability) whereas the lacustrine deposits are generally composed of much finer grained (low permeability) materials. It is this large difference in permeability that is used to distinguish between the sediments of Sierra Nevada origin and those derived from the re-worked sand, silt and shale of the Coast Ranges. Strand-line beach sands, formed at the interface between alluvial-fan and lacustrine environments, are a third type of lithologically distinct deposit. Such deposits, however, are of such limited areal extent that they are relatively unimportant in a regional analysis. As might be expected, the specific areas most prone to the development of drainage problems often lie in topographically lower regions. This is the result of the finer soil constituents, most responsible for poor drainage characteristics, namely silts and clays, typically being carried the furthest distance from their source when in a suspended state. In turn, the rate of deposition of these materials is compounded by the natural tendency of the same regions to act as sinks for the accumulation of water which has fallen within the drainage basin. This suggests that both parent material and topographic controls are largely responsible for the evolution of soils on the West Side of Kern County, and more specifically the formation of those soils favorable to the formation of perched water tables.

The most widespread of the (semi-) impermeable horizons that have been formed in this region is the so-called "E-clay." The E-clay is an extensive, confining stratum of clay, silty clay, silt, and sand. The unit was deposited in a lake which once occupied about 3,500 square miles of bottom land in the western portion of the San Joaquin Valley trough. It occurs from about 250 to as much as 800 feet below the local land surface and is warped into a gently asymmetric, northwest trending syncline, which suggests recent tectonic activity. It has been concluded on the basis of fossil and other indirect evidence that the E-clay is Pleistocene (10,000 to 100,000 BP) in age. This unit represents a deep seated although regionally important aquaclude.

The C and A clay are also fine grained lacustrine and paluda (swamp) deposits but generally occur at depths of less than 100 feet. Structural contours indicate that the deposits are extensively warped and folded. This folding is probably responsible for the discontinuous nature of the numerous near-surface perched water tables formed along the West Side (see Figure 3-15).

More recently (geologically) surface water accumulations have been restricted to the Buena Vista, Kern and Goose Lake basins. The lakebeds themselves are now dry and intensively farmed, though perched water tables are widespread and require artificial drainage networks. The recent introduction of imported State Project water through the California Aqueduct has greatly intensified the perched water conditions and associated salt accumulations in these areas. A two-phased study of the situation by the Kern County Water Association (KCWA) found 37,000 acres beneath which water was found within ten feet of the surface in the northern half of the county (KCWA, 1974) and 57,000 acres of similar condition in the southern portion (KCWA, 1970). Later studies by individual water districts have shown rapid increases in both areas (KCWA, 1975). In one district alone, the less than ten feet to water table acreage estimate increased from 8,000 to 16,000 between 1970 and 1975 (WRM, 1975). Future increases of even greater magnitude are likely, unless a proposed drainage network is implemented, as illustrated in Figure 3-16. Figures 3-17 and 3-18 illustrate the estimated annual crop production losses without a drainage project and the estimated construction costs for a proposed drainage plan. The estimated construction costs of approximately 175 million dollars should be sufficient to illustrate the magnitude of the perched water problem in Kern County. These amounts are also the impetus of present research to more accurately detect and delineate perched water tables by remote sensing techniques, since non-optimal data could dramatically affect the drainage system's operating costs and efficiency.

3.24216 Remote Detection of Perched Water Tables in Kern County

Based on the preceding review of soil parameters related to perched water table accumulations in Kern County, several methods for remote detection and monitoring can be put forth:

- direct detection of soil moisture by passive and active microwave systems;
- indirect detection of soil moisture by thermal infrared systems;
- surrogate detection in the near infrared region from high altitude photographic mapping of soil types and salinity conditions often associated with perched water tables.

The direct detection of soil moisture using LANDSAT imagery has also been examined by our group, but due to the sub-optimal wavelength regions currently available (in terms of soil moisture detection) such imagery requires

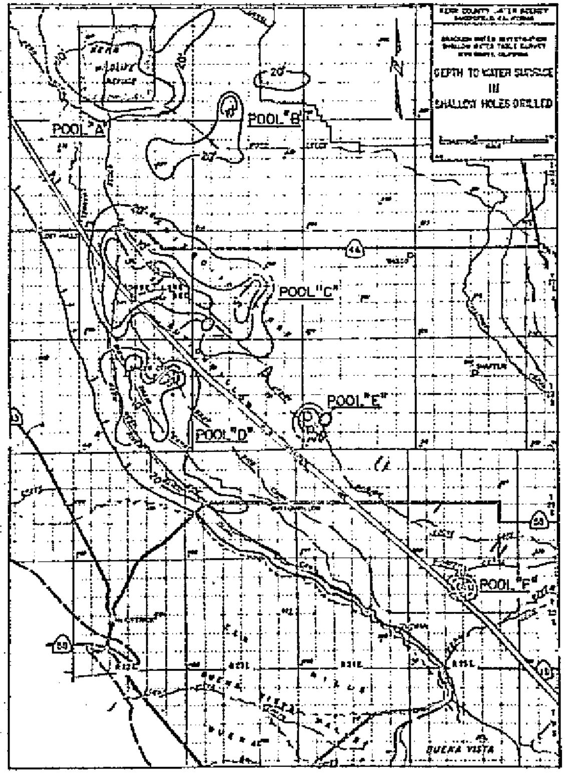


Figure 3-15. Perched water accumulations in Kern County, California (after KCWA, 1974).

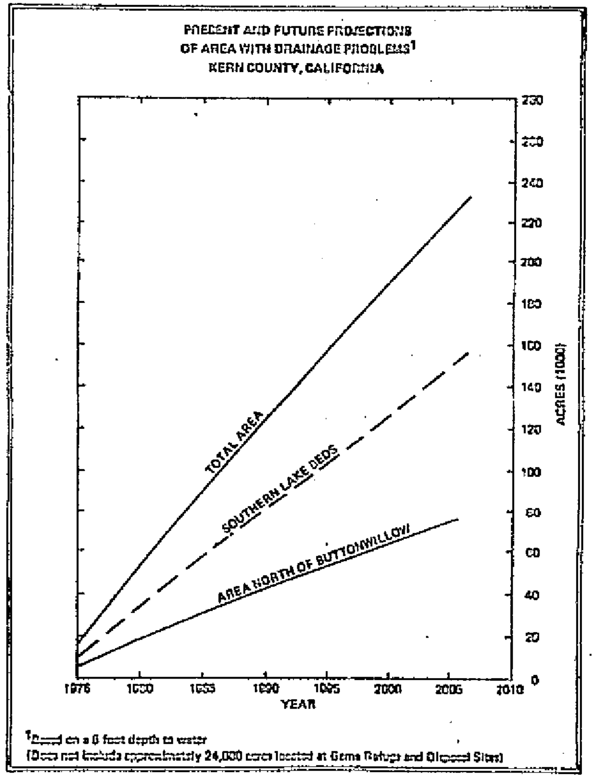


Figure 3-16. Present and future projections of area with drainage problems in Kern County, California (after KCWA, 1975).

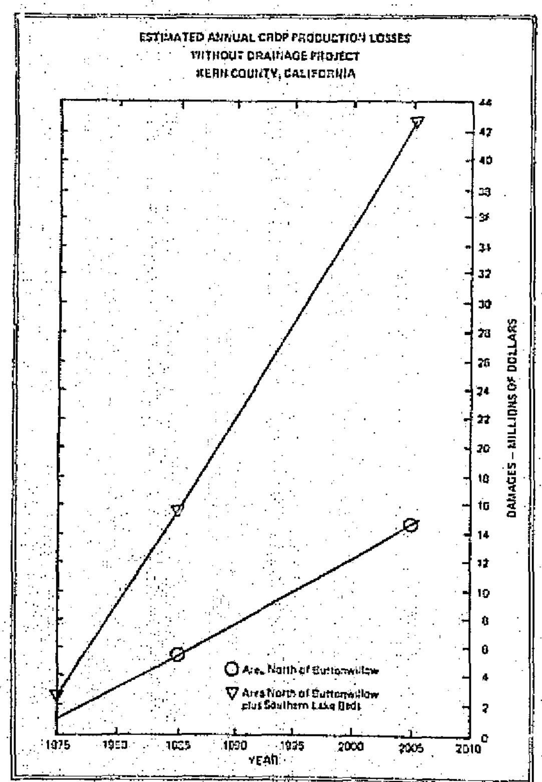


Figure 3-17. Estimated annual crop production losses without drainage project Kern County, California (KCWA, 1975).

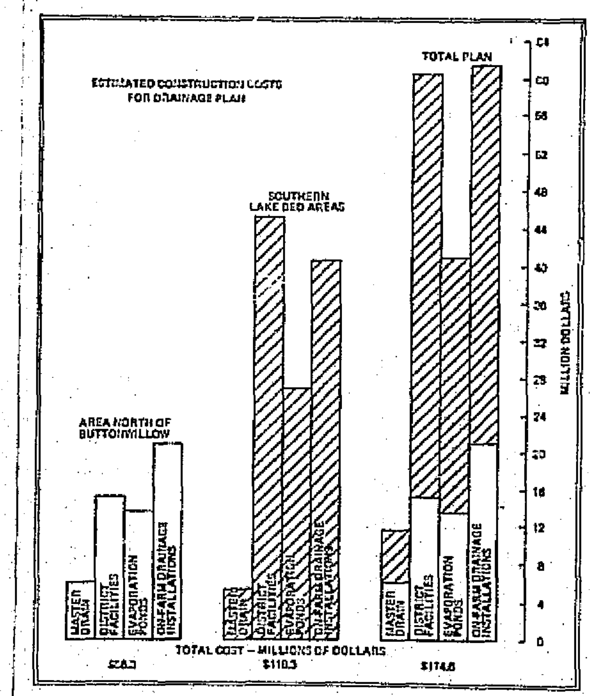


Figure 3-18. Estimated construction costs for drainage plan (KCWA, 1975).

extensive calibration and supporting ground truth information. Figure 3-19 demonstrates a multidate examination of LANDSAT imagery (band 7; 0.8 - 1.1 microns) prior to and after precipitation, an approach considered of potential utility. In semi-arid Kern County, the sparse but predictable precipitation arrives mainly during the months from November to March. Prior to this time uncultivated soils are extremely dry whereas the cultivated soils may remain somewhat moistened due to their irrigation history. It is postulated that for all soils with near-surface perched water tables (e.g. less than 5 feet) an influx of precipitated water will not dissipate as rapidly as those areas without such near surface water accumulations. This should be the case particularly for perched water areas in Kern County where fine grained soils often overlie the water tables. The use of multidate imagery, then, may provide more information than any one single date of imagery. In the case of LANDSAT imagery, as seen in Figure 3-19, the multidate approach may be delineating only soil type variances; multidate microwave and thermal imagery may prove more useful.

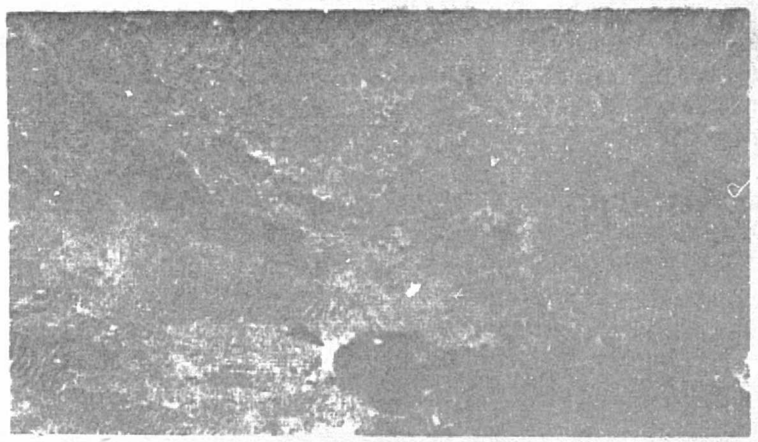
Based on previous research conducted by our group it has been demonstrated that an image created by a passive microwave radiometer is highly correlated ($r = .98$) with the soil moisture of bare soil. This imagery is currently being acquired for GRSU, under contract research by the China Lake Naval Weapons Center, and may in the future be applied to the identification of shallow perched water tables. As yet, however, no flights have been flown specifically over the perched water areas. Based on previous discussion, it should be obvious that surface soil moisture distribution patterns could be an important surrogate for identifying near surface water tables. The rationale for this relationship involves both the slower drainage characteristics previously discussed and the upward movement of water via capillary action.

In December (1975) a NASA aircraft equipped with a side looking radar system overflew two transects in Kern County centered on the Goose Lake and Wheeler Ridge perched water problem areas. Surface soil moisture and soil moisture profile data were collected in conjunction with this overflight. The imagery has been recently received and a quantitative analysis of these data are not yet complete. Based on visual examination it appears that backscatter associated with surface roughness (i.e. soil texture, crop canopy, row direction, etc.) may influence the radar return to such a degree that the derivation of accurate soil moisture data may be difficult, except for possibly bare soil fields and instances of standing water.

A day and night thermal infrared mission covering the known perched water regions of Kern County has also been planned, approved, and currently awaits the operational status of the NASA Ames Thermal Scanner. The rationale behind this overflight is that the surface temperature and/or thermal inertia of soils should allow soil moisture to be estimated. It is anticipated that variations in soil moisture may then prove useful in

MULTIDATE EXAMINATION OF LANDSAT IMAGERY TO IDENTIFY PERCHED WATER TABLES IN KERN COUNTY, CALIFORNIA

24 SEPTEMBER 1974 BAND 7



23 DECEMBER 1974 BAND 7

Figure 3-19. LANDSAT-1 Band 7 images before (above) and after (below) a series of rainstorms in Kern County, California. Note the pronounced enhancement of clay soils in the lowlands of Kern, Buena Vista, and Goose Lake beds (dry). These areas are most susceptible to the accumulation of perched water tables. Image enhancement of the two dates may provide information concerning the areal distribution of soil moisture and soil type which may act as surrogates for detecting the distribution of near-surface perched water tables.

monitoring the dimensions of perched water table areas in Kern County. In conjunction with Dr. Algazi's group we shall also be examining, in the near future, thermal imagery obtained from the NOAA-2 meterological satellite. This imagery will of course be of much lower resolution but its multidate availability may prove useful for further technique developments.

Our group has previously mapped suspected perched water tables using NASA (1:125,000) color infrared photography. Though encouraged by initial results (i.e. approximately 60% overall accuracy for identifying subsurface water $\leq$ 20' below the surface), it has been difficult to improve accuracies using such photography. The primary discriminant of near infrared imagery is related to its ability to identify the organic clay soil types (a good surrogate for perched water tables in Kern County) and standing water occurring where the water table extends to the soil surface. Therefore, the color infrared photographic inventory of near-surface perched water tables is totally dependent on the reflected energy component from soil or standing water, with no direct capability to detect subsurface water.

Color infrared photography has proved useful for detecting saline soil conditions in Kern County. Perched water tables are a common cause of saline conditions; therefore, such conditions may prove useful for generally delineating areas with drainage problems. It has been noted by KCWA personnel that:

> "Crop yield reduction exceeding 25% was noted on [all] lands where water was found within 5 feet of the land surface and on nearly all lands with "perched Water" at 10 feet or less."[1]

One problem that might be encountered when using salinity as a surrogate is that the dynamic nature of perched water accumulations may not be adequately observable through such secondary effects. As our research concerning salinity progresses we shall explore this potential surrogate to determine if this is the case.

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[1] Kern County Water Agency. "Summary Report on Agricultural Wastewater Collection and Disposal System Kern County, California," November 1975.

3.2422 SOIL SALINIZATION

3.24221 Capillary Rise

Drainage related problems, such as salinization, are typically intensified in arid environments such as Kern County. Quite simply, evaporatranspiration rates are higher; hence, the potential for salts to accumulate within the soil is greater. "The process of evaporation inevitably results in the deposition of salts at or near the surface of the soil. These salts can be removed or prevented from accumulating <u>only</u> if the water table remains deep enough to permit leaching without subsequent resalinization through the capillary rise of the groundwater."[1]

The zone of soil just above the water table which is still essentially saturated although under suction may be defined as the "capillary fringe." Capillary rise from perched groundwater tables can substantially affect salinization, especially where groundwater is brackish to begin with and potential evaporation is high. In fine textured soils, the hazard of salinization can be substantial; even in those areas where the water table is several meters deep. Since capillarity is generally restricted to the smaller or micropore spaces within a given soil, the relationship to finer textured soils should be apparent. Table 3-17 shows values for the height of capillary rise for some typical soil types.[2]

TABLE 3-17

Height of Capillary Rise in Some Soils

Soil	Height (cm)
Clay	200-400
Sandy Loam	150-300
Sandy Soil	100-150
Sandy Uppersoil	50-100
Podsol	35-40
Peat	120-150

Owing to this differential capillary rise in soils of varying types it can be seen that the depth to the water table is very influential in controlling the amount of evaporation possible through the capillary rise of soil water. Figure 3-20 illustrates this effect for a fine, sandy loam soil.

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1 Hillel, Daniel, op. cit.

2 Polubarinova-Kochina, op. cit.

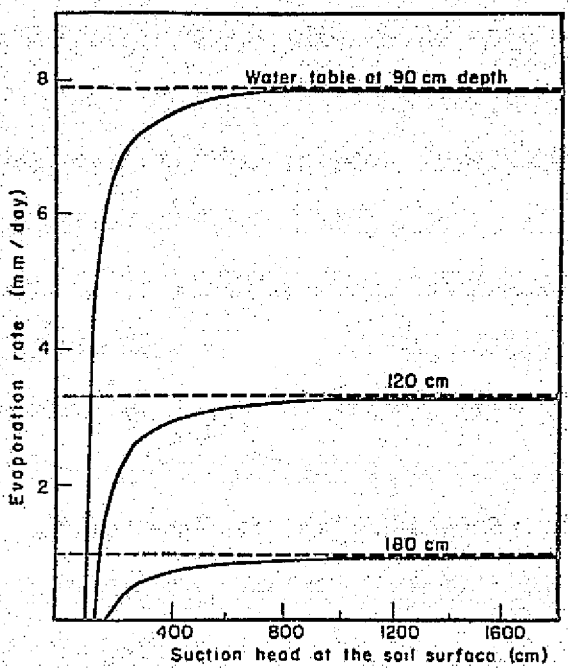

Figure 3-20. Capillary rise of soil water in fine, sandy loam soils.

3.24222 Salinization in Kern County

In recent geologic times surface water accumulations have been generally restricted to the Buena Vista, Kern, and Goose Lake basins in Kern County. Extensive surrounding areas with shallow water tables became salinized during this period. Before the present system of dams and reservoirs on major streams emptying into the Southern San Joaquin Valley, and the use of surface water for irrigation, these lakes typically overflowed a low alluvial divide into the San Joaquin River and thence to San Francisco Bay. These periodic overflows, the last of which occurred in 1877, flushed large amounts of accumulated salts from the lakebeds, maintaining some semblance of salt balance.[1] These overflows also impeded the formation of playas or salt lakes which are common to basins of interior drainage in arid environments, e.g. the Great Salt Lake basin of Utah. Since the gently sloping margins of these lakes (Buena Vista, Kern and Goose) were not subject to the same amount of flushing action, the soils in these areas accumulated significantly greater amounts of salts. It is these soils which are presently the most unfavorable for agriculture in the valley floor. A major problem resulting from the lack of periodic overflows into the San Francisco Bay is that the Southern San Joaquin basin is now essentially closed with an estimated accumulation of approximately 500,000 tons of salt per year.

Therefore, the increased salinity problem of the San Joaquin Valley portion of Kern County can be attributed to the following factors:

- it is essentially a closed system of interior drainage, as no flushing to the San Francisco Bay is at present possible;
- increasing amounts of applied surface water, i.e. California Water Project, Friant-Kern Canal, etc., has raised the water table in the topographically lower parts of the valley;
- due to the existence of impermeable clay lenses the water table is $\leq$ 10' below the surface for extensive areas.
- groundwater perched on these aquacludes is brackish due to the high evapotranspiration rate in the valley and the numerous times the water is pumped from aquifers which underlie the valley floor and reapplied to cropland;
- with brackish perched water $\leq$ 10 below the surface expanding in the West Side trough, the capillary rise of soluble salts is creating serious problems affecting agricultural yield

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[1] California Department of Water Resources (DWR), "Land and Water Use Aspects of San Joaquin Valley Drainage Investigation," Memorandum Report, June 1970.

- to effectively reverse this trend a master drain must be constructed so effective leaching of soluble salts can take place;

- remote sensing can take an active role by developing techniques which can: 1) identify the perched water areas; 2) identify and predict soil salinity; 3) predict the leaching water demand to rid the soil of the harmful soluble salts.

3.24223 Remote Detection of Soil Salinity in Kern County

At present, conventional techniques for gathering salinity data in agricultural environments involve costly field sampling procedures. GRSU is developing a remote sensing methodology whereby salinity data may be generated on a per-field basis from high altitude photography. Such data can serve as input to hydrology models by providing an estimate of the amount of water necessary to effectively leach saline soils. This could result in keeping more land in economic production and/or facilitate the prediction of agricultural yield decrement and dollar loss due to salinity. Kern County Water Agency is particularly interested in expanding the present groundbasin model to perform salt balance computations (Appendix 1).

The basic hypothesis of our salinity prediction procedure is that there is a correlation between the condition of crop present and the soil salinity of the field. The University of California Agricultural Extension Service has published a number of reports which list the yield decrement to be expected from certain crops due to specific soil salinity values.[1] Yield decrement data compiled jointly by KCWA and GRSU personnel has also substantiated the existence of a negative correlation ($r = -.76$) between salinity and cotton yield in our study region. This data was presented in the May 1975 report.

Several of our preliminary attempts at quantifying visual salinity damage were hampered by the range of tonal values exhibited by healthy fields. This range of values can be attributed to any one or a combination of variables including: the various sun angles between individual fields and the observation platform; vignetting effect of the camera lens; soil type variations (including but not limited to soil salinity); and differing cultivation practices, e.g., fertilization, irrigation, etc. To reduce the effects of variations attributed to these variables a procedure has been developed whereby a "healthy" portion of each field is selected and used as the basis for quantifying damage in the remaining portion of the field. Each field is individually examined on high altitude photography

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[1] University of California Agricultural Extension Service, Kern Crop Information, U.S. Department of Agriculture, November 15, 1973.

and digitized. Once the original field is digitized, a healthy sample area within the same field is located. For this healthy sample area, mean and standard deviation statistics of tonal values are calculated. These statistics are then expanded to the full field area (based upon the total number of digitized picture elements, i.e. pixels) using the normal probability density function where:[1]

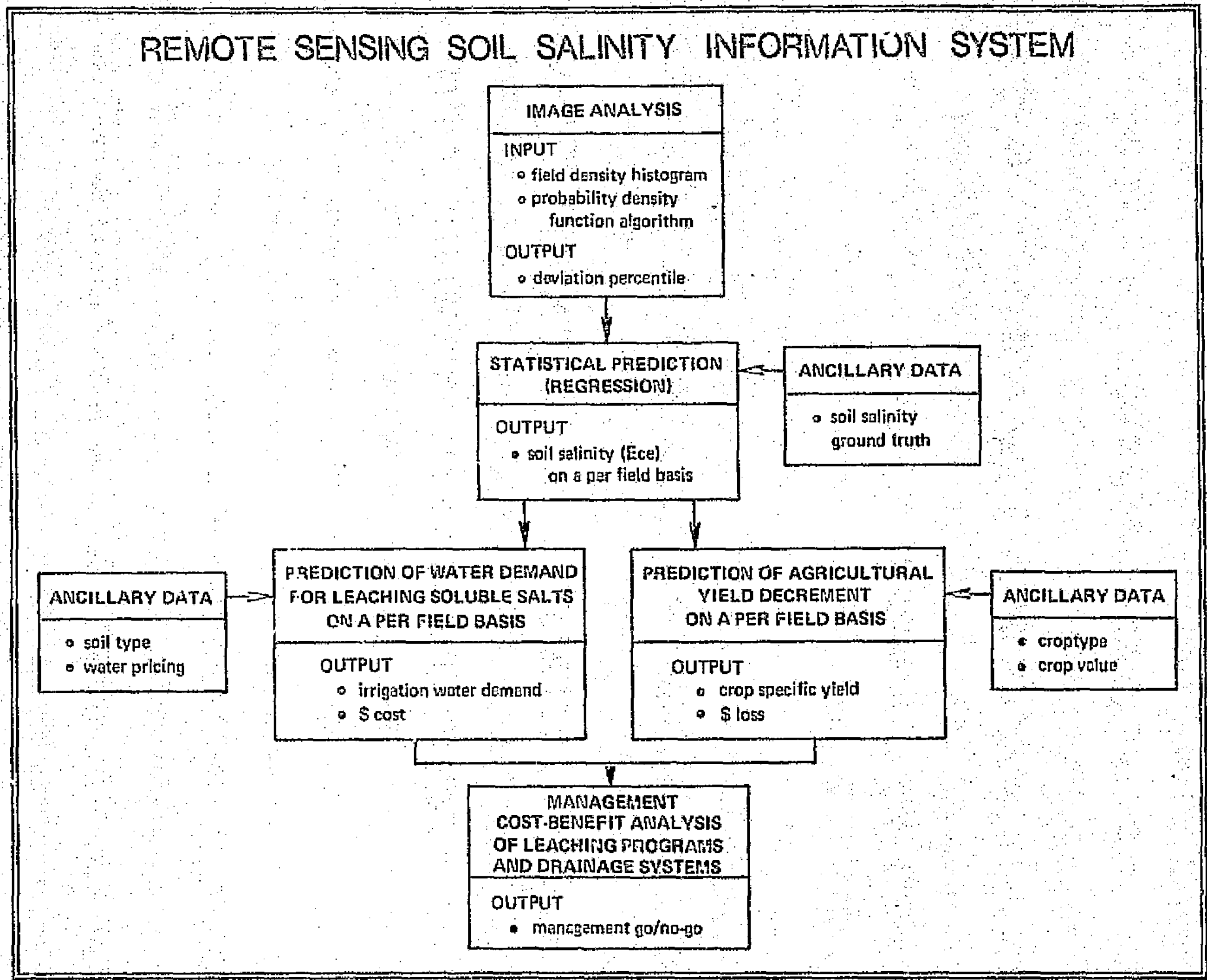
$$Z = \frac{1}{\sigma\sqrt{2\pi}} e - (Y-\mu)^2/2\sigma^2$$

Z = height of the ordinate of the curve, representing the frequency of the items
Y = variable in question, in this case the optical density of the photograph
μ = parametric mean of sample
σ = parametric standard deviation of sample
π = pi
e = base of Naperian logarithms

This function determines the frequency histogram of the sample healthy area. When multiplied by the number of pixels in the full field these frequency values generate the distribution that would be expected if the full field had the statistical characteristics of the healthy sample. An assumption is made that a healthy field or sample area will have a fairly normal distribution of tonal values. This assumption is strongly supported by our preliminary analyses. Once the expected healthy distribution of tonal values is obtained these values are subtracted from the actual field tonal values and the absolute values of the difference are summed. This assures that positive and negative differences do not cancel out one another, which would otherwise result in a summation value of zero. Division of this difference value by 2X the total number of pixels results in a value that will range from 0.0 to 1.0 depending upon the similarity of the healthy sample to the total field. A value of 0.0 would imply totally similar statistics while a value of 1.0 means no overlap in the range of values. For convenience, these values can also be converted into percentages (0-100%) and termed the "deviation from normal field densities."

As detailed in Figure 3-21, the salinity (Ece) prediction technique requires soil salinity ground truth data in order to assess prediction accuracies in a regression mode. To obtain this data GRSU has resorted to expensive, conventional soil sampling procedures. The initial analysis of this conventional ground truth (ece) data and the "deviation from normal field density values" resulted in an encouraging positive correlation coefficient (r = .79) for 13 intensively sampled cotton fields totaling approximately 1500 acres (May 1975 Annual Progress Report).

[1] <u>Biometry</u>, by R. Sokal and F. Rohlf, W.H. Freeman and Company, 1969.



Geography Remote Sensing Unit, University of California at Santa Barbara

Figure 3-21. This diagram illustrates the potential uses of remotely sensed salinity information in terms of water demand, yield decrement, and management cost-benefit decision making.

Since the last reporting period GRSU has been concerned with the expenditure associated with acquiring the required soil salinity ground truth information. To alleviate this problem we have been in contact with the Buttonwillow Warehouse, an agribusiness which sub-contracts with agriculturists throughout the West Side of the San Joaquin Valley to take soil samples. The data gathered by this agribusiness will now serve as the ground truth information for the salinity prediction procedure. The GRSU has just recently obtained the laboratory soil analysis data for approximately 150 fields, approximately 10,000 acres. As illustrated in Table 3-18 this data is very inclusive and will allow a rigorous test of the soil salinity prediction procedure to be made. This data is made available (at what would otherwise be $30 per field) because Buttonwillow Warehouse is interested in a remote sensing technique which could predict soil salinity or aid their sampling schemes. Based on this newly acquired ground truth salinity data, the following data analyses are about to be initiated. First, the fields to be subjected to image analysis will be stratified according to field condition (i.e. croptype or fallow), and soil type. With deviation precentages generated and ground truth available for these fields it will be possible to utilize linear regression, and hypothesis testing procedures to determine if there is a significant statistical difference in the ability of the remote sensing procedures to accurately predict soil salinity when the field under investigation is:

- vegetated or fallow (i.e. is the technique more accurate when the field is vegetated with a specific crop or when it is fallow?)
- situated on a particular soil type (e.g. is the technique more effective on silt soils versus loam soils?)

Therefore, by the next reporting period this data will have been analyzed in light of the deviation percentages data and confidence limits placed on the salinity prediction procedure.

If this remote sensing soil salinity prediction procedure proves to be a reliable technique, then two logical uses of such data would be the prediction of leaching water demands and agricultural yield decrement (Figure 3-21). The prediction of water demand for leaching soluble salts on a per-field basis requires that soil salinity, soil type, and water pricing data be available. In order to leach soluble salts down 1 foot it ordinarily requires that at least 1.5 acre-feet of water be applied. This leaching water demand is, of course, dependent on the regional soil characteristics previously discussed. When the amount of leaching water required per field is determined and multiplied by the cost per acre-foot, the cost of leaching can then be determined. This leaching water demand prediction, however, must not be considered in the same light as an agricultural water demand prediction. This is because the water required to leach out the soluble salts may never be applied simply due to the perception of landowners as to how to best manage their land. Conversely, irrigation water for specific crops must be applied. Therefore, the salinity leaching requirement may be considered a latent water demand in contrast

to the dynamic agricultural water demand for specific crops.

Although not related to water demand, the prediction of agricultural yield decrement due to salinity would be a very important use of the prediction techniques. Once the soil salinity (Ece) on a per field basis can be predicted for a given croptype, the potential yield decrement of that particular crop for that level of field salinity can be predicted by referring to appropriate yield decrement tables. This statistic coupled with market values for yield can generate either the expected crop value or the dollar loss due to soil salinity.

The analysis of both leaching water demand and the expected yield decrement due to salinity for a given region should improve management decisions concerning the cost-benefit of proposed leaching or drainage programs.

TABLE 3-18

AGRICULTURAL TECHNICAL SERVICE ATS

APPLIED ENTOMOLOGY SOIL & PLANT NUTRITION LABORATORY

P. O. BOX 2141, BAKERSFIELD, CALIF. 93303 - (805) 366-8444

Reported To : Buttonwillow Warehouse
Submitted By : same
Identification: wheat & cotton

Laboratory No. : 5291
Date Submitted : 11/29/74
Date Reported : 12/11/74

REPORT OF SOIL ANALYSIS

DESCRIPTION		SP	pH	EC	Solu. Cat. Ca%	Mg%	epm Na	Gyp Req.	Lime-stone	SAR	ESP	ppm B	ppm in dry soil NO3-N	PO4-P	K	Zn	Mn
39-BR	2	44	7.6	7.9	46	4	40.0	none	30000	9.1	10.8	0.7	44	14	550	1.0	5.7
39-GCR	1E	69	7.8	2.3	24	6	16.1	"	17000	8.7	10.3	0..1	14	4	420	0.4	4.0
	1W	70	7.6	7.0	39	5	39.6	"	69000	10.2	12.1	1.0	22	8	510	2.4	3.0
	2E	79	8.6	3.0	3	1	28.7	14.9	54000	35.6	33.9	1.9	13	4	480	0.4	8.0
	2W	90	7.8	10.5	25	4	74.6	1.5	7000	19.1	21.2	2.2	7	12	510	0.6	2.6

Laboratory soil analysis data now available from the Buttonwillow Warehouse in Kern County, California.

3.30 SPECIAL STUDIES

3.31 Santa Barbara County Crop Study

A Santa Barbara County croptype inventory (see Figure 3-6) has been initiated on a $4,000 matching fund basis with the Santa Barbara County Water Agency. The investigation is attempting to identify problems associated with the accuracy and cost-effectiveness of high altitude and/or LANDSAT cropland and croptype inventories in this non-arid environment. A county-wide ground truth survey of the 1975 field-by-field croptype has been completed as the initial phase of the project. This information will serve the dual purpose of providing an accurate data base for:

- the investigation of the potential of LANDSAT imagery for future cropland and croptype inventories;
- Phase I of the Santa Barbara County Water Agency's 1975 Water Resource Planning Program which includes a determination of current water demand, as well as a projection of future water demand.

The mapping of crop field boundaries for this study was done from high altitude, scale 1:32,500, 1:62,500 and 1:125,000 color infrared photography. Interpreted data was transferred optically from the imagery to 7.5 minute USGS quadrangles. These maps provide a planimetrically accurate base from which information on the areal extent of specific categories of land cover can be obtained. With these field boundaries delineated, a county-wide field crop survey was undertaken by GRSU and water agency personnel during the summer of 1975. The agricultural classifications were made according to the State of California, Department of Water Resources Land and Water Use Survey system, which identified nine major categories of land use:

1- truck crop
2- field crop
3- irrigated pasture
4- citrus and avocado
5- deciduous fruit and nut
6- vineyard
7- ornamental
8- grain
9- semi-agriculture

Although the water agency required that the croptype data be aggregated to this level of generality, GRSU personnel conducting the field verification identified each specific crop for the entire county study area for the purposes of assessing future automated cropland and croptype inventories. Parameters to be analyzed with regard to the potential for satellite crop inventories in this type of environment are the effects of different:

- crop species and phenological cycles (crop calendar)
- field size and geometry
- cloud cover distribution
- bureacratic and temporal requirements

In terms of distinguishing specific croptype information more than 40 different crop species are grown in Santa Barbara County, making crop identification a much more complex task than in Kern County, California. In addition, the growth cycle is markedly different between the two counties with similar species being planted and harvested at different times.

The varied topography of Santa Barbara County agricultural land presents the problem of delineating fields that follow the terrain contour rather than a systematically surveyed rectangular system. These physiographic factors have also led to the creation of fields as small as two acres.

In addition to these problems associated within terrain, the climatic variation encountered in this region creates a diversity of cloud cover conditions, necessitating the use of multidate imagery for crop inventories. The more temperate climate also influences the amount of water required by each species, therefore affecting water demand prediction.

Information generated by this special study will be available to all interested agencies at the local level. The extensive cooperation between the Santa Barbara County Water Agency, Agricultural Extension Office, and the GRSU is facilitating the success of the project. The final product of this study will be the development of a methodology that can be transferred to local agencies for cost-effective cropland/croptype inventories in Santa Barbara County, hopefully from satellite imagery. To this end, a detailed record has been kept of the time, cost, procedure, and accuracies involved. The priority use of crop type data is for water demand prediction but will be utilized in numerous modes by other county agencies.

3.320 Goleta Groundbasin Permeability Study*

3.321 Introduction

In the May 1975 Annual Progress Report a groundbasin permeability study was proposed. This special study has been initiated and funded by the Santa Barbara Office of Environmental Quality to determine the usefulness of remote sensing techniques for identifying both the type and amount of permeable surfaces overlying a predominantly urban groundwater recharge basin.

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* Tinney, L.R., Jensen, J.R., and Estes, J.E., "Urban Land Use: Remote Sensing of Groundbasin Permeability," presented at the First Earth Resources Survey Symposium, Houston, Texas, June, 1975.

The areal extent of the groundwater basin (see Figure 3-22) is approximately 10 sq. miles. This basin provides an estimated 20% of the water currently used by the Goleta County Water District. Goleta County Water District supplies water to an unincorporated urban and rural population that has increased nearly 700% during the last twenty years and is currently estimated at 72,000. This dramatic population increase, coupled with limited local water supplies, has resulted in the implementation of a building moratorium which has been in effect for the past two years. Of crucial concern to any litigation concerning this moratorium in particular, and to water district management in general, is the safe or sustained yield[1] of the Goleta water basin. The safe yield of a groundwater basin is directly dependent upon the type, amount, and spatial distribution of permeable surfaces overlying the recharge portion of the basin.

Two previous studies detailing the geology and safe yield of the Goleta groundwater basin are considered outdated.[2,3] This relative obsolescence is in part due to the effects of increasing urbanization which commonly changes a basin's peak flow characteristics, increases total runoff, and often adversely affects groundwater quality. Figure 3-23 graphically illustrates an example of the general increase in the number of overbank flows, a factor related to both peak flow and total runoff, that might be expected with increasing urbanization.

Table 3-19 shows the dramatic increase in sediment yield commonly found as one goes from rural to urban landscapes.[4]

TABLE 3-19

	Drainage Area (sq. miles)	Sediment	
		Tons Per Year	Tons Per Year Per Sq. Mile
RURAL (Watts Branch in Rockville, Md)	3.7	1,910	516
URBAN (Little Falls Branch near Bethesda, Md.)	4.1	9,530	3,220

1 "Long-term sustained yield is a rate of withdrawal equal to the sum of changes in recharge and discharge that take place as a result of withdrawals and lowering of water levels by pumping" Water Resources Council, "Essentials of Ground-Water Hydrology Pertinent to Water Resources Planning, Washington, D.C., August 1973, 48p.

2 Upson, J.E., "Geology and Ground-Water Resources of the Southern Coastal Basins of Santa Barbara County, California, with a Section on Resources" by H.G. Thomasson, Jr., U.S. Geological Survey Water Supply Paper 1108, 1951, 144p.

3 Evenson, R.E., Wilson, H.D., Jr., and Muir, K.S., "Yield of the Carpinteria and Goleta Ground-Water Basins, Santa Barbara County, California," 1941 to 1958: U.S. Geological Survey Open File Report 112, 1962.

4 Leopold, L.B., "Hydrology for Urban Land Planning-A Guidebook on the Hydrologic Effects of Urban Land Use," U.S. Geologic Survey Circular 554, 1968, 18pp.

The research presented in this paper was conducted by GRSU personnel as part of a study by the Santa Barbara County Office of Environmental Quality to revise previous estimates of the Goleta Basin's safe yield. The initial stage of our research involved the detailed delineation of permeable and impermeable surfaces on low altitude conventional black-and-white photography. Impermeable surfaces were broadly defined to include roads, parking lots, etc., while permeable surfaces were more specifically categorized as to their type. This information was manually transferred to overlays and automatically mensurated by a video image analyzer capable of density slicing and digital planimetering. Accuracies and costs associated with this technique have been documented and compared to more conventional approaches.

Data generated during this initial research phase is currently being used to provide reliable training samples for a pattern recognition analysis of high altitude color infrared photography. The spectral signatures of these samples are providing the statistics by which the remaining portion of the study area will be automatically classified. Previous automatic classifications of impervious surfaces have been hampered by a lack of reliable data against which the classifier results can be compared. The extent of this study area and amount of photointerpreted data available to this study are such that a more reliable assessment of classification accuracies can be achieved. Preliminary analysis of the results of our pattern recognition research discussed later, are considered encouraging.

3.322 Methodology

Trained image interpreters were employed to classify and categorize data present on the black-and-white imagery. The interpreters were asked to classify the various land uses into four categories. The categories were:

1. *Non-permeable surfaces:* generally defined to include roads, roofs, parking lots, and other impervious surfaces.
2. *Permeable surfaces:* specifically defined as
   - 2a. Lawns,
   - 2b. Irrigated agriculture, or
   - 2c. Native vegetation and open space

These initial interpretations were accomplished from low altitude conventional black-and-white photography flown in June 1974 and printed at a nominal scale of 1:7,200. Acetate overlays were placed directly upon the photographs and three of the four classes were color coded by the image interpreters. Owing to the suburban nature of the Goleta environment, the most detailed category was lawns; this category was left clear. The overlays were then subdivided into 3 inch square cells suitable for analysis by the video image analyzer.

The color coded overlays were then density sliced by the video image analyzer to take advantage of this system's electronic planimetering

capability. By the selective use of color filters placed between the video camera and the color coded overlays a potentially large number of classes can be distinguished by their tonal density values alone. Such a procedure, especially when combined with a pattern recognition algorithm, may also provide the basis for thematic map encoding, as discussed by many land use information system proposals. The procedures developed and utilized in connection with this project proved highly efficient, requiring less than one day of labor to extract all four class area estimates, on a grid basis for the entire ten square mile study region.

Figure 3-24 illustrates a two-class example, as interpreted from the low altitude photography, including 1) the original photography, 2) the photo interpreted overlay of the scene, and 3) the corresponding video enhancement and digital planimeter values. Table 3-20AB summarizes the results of this analysis for the entire Goleta recharge basin.

TABLE 3-20A

GOLETA RECHARGE BASIN: ACREAGES

Class	Western	Central	Northern	Eastern	Total
	Sub-Basins				
1 Impermeable	357	1,134	209	695	2,394
2a Lawns	204	622	164	450	1,440
2b Irrigated agriculture	135	234	112	76	557
2c Open space and natural vegetation	648	594	203	399	1,845

TABLE 3-20B

GOLETA RECHARGE BASIN: PERCENTAGES

Class	Western	Central	Northern	Eastern	Total
	Sub-Basins				
1 Impermeable	27	44	30	43	38
2a Lawns	15	24	24	28	23
2b Irrigated agriculture	10	9	16	5	9
2c Open space and natural vegetation	48	23	30	24	30

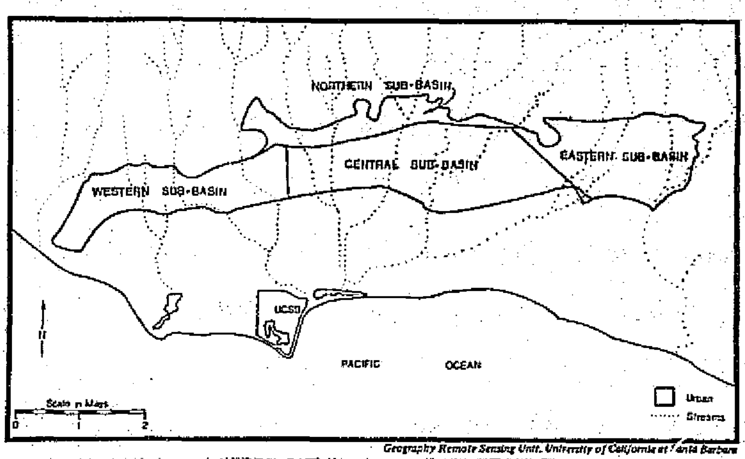

Figure 3-22. The Recharge Basin of Goleta Valley, California. The stippled pattern delineates urban areas.

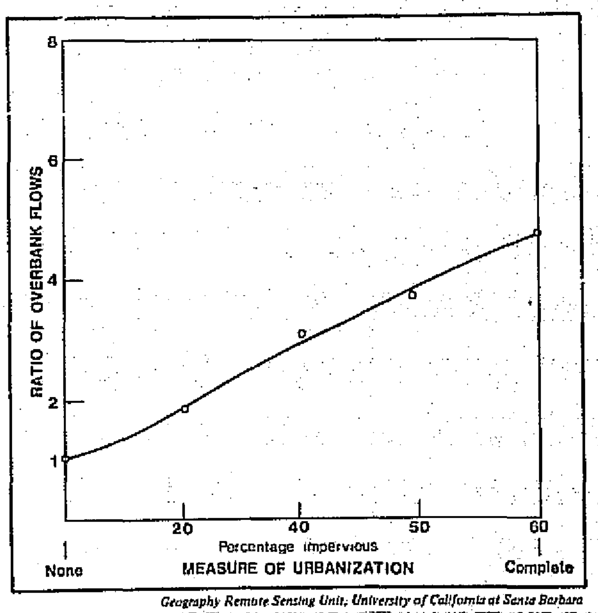

Table 3-23. Relationship between percentage of impervious surface and ratio of overbank flows (adapted from Leopold, 1968).

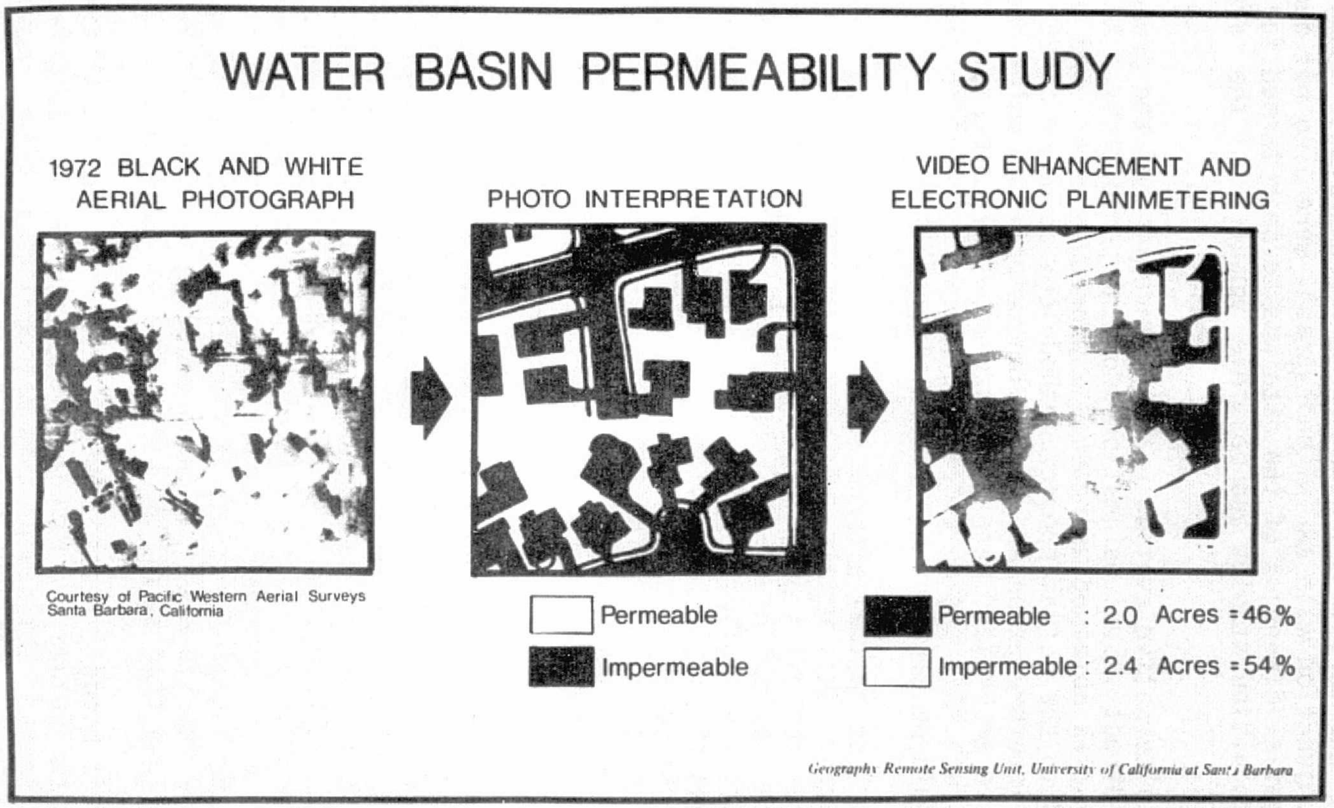

Figure 3-24. Permeability study methodology.

3.333 Analysis of Alternatives

In addition to the techniques discussed above, various alternative methodologies were available for supplying the information required for the Goleta Basin safe yield study. Extensive field investigations were definitely prohibited due to both time and monetary constraints. Sampling techniques used in conjunction with aerial photography were also not deemed appropriate as the spatial dimension of the data was to be retained for our automatic pattern recognition studies and possible "updates" of the safe yield in the future.

The most viable alternative available at the inception of the project was considered to be direct visual estimation from the photography. An analysis of the accuracies obtained using such a procedure were found to be 86% accurate compared to the actual project methodology accuracy of 98% which involved image interpretation and video planimetering of color coded overlays. It should be emphasized here that when monetary, accuracy, and time constraints are such that the more detailed analysis is not feasible, this visual option could be considered a viable alternative.

Another somewhat less optimal alternative is visual estimation from the color coded overlays. This resulted in accuracies, of 95%. This technique, however, still involves the major project expense of interpreter overlay compilation. Once the overlays have been generated the video enhancement and planimetering costs are negligible (less than 8 hours labor for the study region), provided the analyzing equipment is available. The alternative of manually planimetering each class was found infeasible at the original imagery scale due to the intricate nature of the class distributions. Indeed, this intricacy presented an obstacle to evaluating the relative accuracies of the various procedures by necessitating the photographic enlargement of selected scenes to scales more easily planimetered.

The most automated technique examined, which is still under investigation, involves the application of a pattern recognition algorithm to a digitized representation of color infrared photography. A maximum likelihood algorithm trained on samples of the four classes has been used to classify a small portion of a NASA high altitude color infrared photograph. When the lawns,irrigated agriculture, and open space in this study area were aggregated to one permeability class, a mean classification accuracy of 75% was achieved. The major assignment to permeable classes appears to be based primarily upon the high reflectance of vegetation in the infrared spectral region. These results are considered encouraging, though preliminary in nature as less than 5% of the study area was analyzed.

Present research is being directed towards expanding these preliminary results and assessing the nature and extent of the major variables affecting both accuracy and the transferability of this methodology to other regions.

3.334 Conclusions

This research has documented an effective methodology to accurately generate quantitative urban groundbasin data useful for determining safe yield values. The extensive amount of accurate data generated by this project from low altitude photography has provided a reliable basis against which automatic techniques, based upon high altitude color infrared photography, can be evaluated. The methodology utilized for this project takes advantage of an image interpreter's ability to precisely delineate permeable from impermeable surfaces in complex urban environments, and a video image analyzer's ability to accurately and rapidly extract quantitative area estimates for assigned classes. Analysis of our results by the cooperating user agency, the Santa Barbara County Office of Environmental Quality, has just begun. As close user-researcher contact has been maintained throughout this study a favorable user response is anticipated. If successful, approaches such as those discussed herein will significantly reduce the time and effort involved in generating permeability data, an important aspect in determining urban hydrology dynamics.

3.40 FUTURE WORK

Future GRSU research will entail work on the following topics:

- A district or county-wide remote sensing-based estimates of agricultural water demand will be compared with conventional estimates, cost, and accuracies

- A detailed cost-effectiveness comparison between LANDSAT croptype inventories and the California Department of Water Resources (DWR) croptype inventories will be initiated. Data is currently available from DWR for the Kern County region.

- An analysis will be made of benefits derived from the use of more accurate, timely, remote sensing croptype water demand information when applied to the KCWA model. Dedicated runs driven by remotely sensed water demand data will be compared to hydrologic predictions based on conventional historical data. In this manner GRSU will begin to answer work items 2, 3, and 7 in a quantitative manner.

- The applicability of semi-arid environment agricultural water demand prediction procedures will be tested in the more temperate Santa Barbara South Coast region. The goal is to identify specific parameters to be incorporated and problems which must be solved to effectively transfer the procedure to a different environment and land tenure system. This research will go forth in terms of the Santa Barbara County croptype inventory discussed in section 3.410.

- The remote detection of perched water tables will utilize thermal infrared overflights or multi-date LANDSAT band ratioing.

- The refinement of the remote sensing salinity prediction procedure will be initiated, based on the substantive ground truth information now available.

- In conjunction with the Riverside and Berkeley Groups, GRSU will develop additional LANDSAT remote sensing techniques pertinent to California Department of Water Resources (DWR) water demand forecasting. Specifically, DWR has indicated that perhaps their statewide water demand forecasting could be predicted from knowing only level one land use classification data (i.e. irrigated land, irrigable land, and urban). However, this thesis needs to be researched and documented.

CHAPTER 4

USE OF REMOTE SENSING TO INVESTIGATE WATER RESOURCE ALLOCATION IN SOUTHERN CALIFORNIA

CHAPTER 4

USE OF REMOTE SENSING TO INVESTIGATE WATER RESOURCE ALLOCATION IN SOUTHERN CALIFORNIA

Co-Investigator: Leonard W. Bowden, Riverside Campus
Contributors: C. Johnson, D. Nichols, J. Drake, G. Thomas, A. Van Curen

4.0 INTRODUCTION

Southern California is a region in which the allocation of water resources can have far reaching implications in the economic, social and geographic sectors. On one hand, imported water serves for the most part, as the economic life-blood of the region in that it is vitally needed for both agricultural and domestic purposes. On the other hand, Southern California has a large though inadequate water supply of its own. The relationship of these two water supply sources affects the quality of life and to some extent the food supply of this highly populous area.

Remotely sensed data sources appear to be able to provide cost-effective information relevant to assessing pressures brought to bear on these water resources. It is in light of the general water resource allocation problems of Southern California that several planning techniques are applied and described below which rely heavily on NASA remotely sensed imagery. Included are specific investigations which evaluate and demonstrate the use of remote sensing for estimating water demand for the Upper Santa Ana River Basin.

Another important resource is the Southern California coastal zone where population pressure for housing and recreation competes with any attempt to preserve the ecological balance of a fragile resource. In a way, the coastal zone is just another extension of the complex California water resource management problem. Also reported in this chapter is research performed by our University of California, Riverside scientists as they have sought to develop applications of remote sensing toward the solution of problems in California's coastal zone.

4.1 Current Studies in the Use of Remote Sensing to Determine the Water Demands of the Upper Santa Ana Basin

4.1.1 Introduction

Water use displays a spatial co-variance with land use types. Therefore land use patterns are invaluable in estimating overall water demand and understnading the spatial component of water demand. As changes in land use are monitored, a temporal aspect is added which, combined with the spatial information, is useful for the making of long

range decisions regarding water resource demand.

The use of high altitude remotely sensed imagery to determine long-term water demand through analysis of land use is proving to be most effective. The California State Department of Water Resources (DWR) has, for many years, forecasted long-term water demand by an empirical model that utilizes net land use as the driving parameter. The results of research conducted by our U.C. Riverside remote sensing personnel both improve the model in accuracy and provide rapid output of results.

The development of water demand information for the Upper Santa Ana River Drainage Basin has led to three related studies. The first of these is a machine-assisted land use study. It is necessary to identify the land use of the basin because how the land is used constitutes the driving factor in modeling where and how the water is or should be used, as well as how this mix changes through time. The second study is a population-oriented one and entails stratification of the area based on per capita water use and population density. For estimating current non-agricultural water demand in selected service districts, DWR utilizes a combination of population and water delivery/connection data. This yields a per capita water consumption statistic. Because population estimates are aggregated, the per capita figure is generalized over a large area and does not often correspond with DWR planning units. Remote Sensing used in conjunction with census data for producing disaggregated, updated population data and per capita water use, is the subject of this second study. Our third study more closely examines the temporal aspects of water demand for agricultural purposes in this area. The study was brought about as a result of the Department of Water Resources' particular concern with agriculture and related water supply problems. As a demonstration, two projects are being carried out. The first involves an identification of the citrus crop over a period of time in order to be able to assess regional trends with respect to water supply needed for that particular crop. The second project was specifically requested by DWR and seeks to determine the number of months during which irrigated agricultural fields are idle. Agricultural water demand estimates made by the DWR are made with only a fair guess as to the duration of the inactive season. Because agriculture represents 33% of the land use in the basin, the accuracy of predicting the inactive season can made a considerable difference in the overall water demand estimate.

4.1.1.1 Objective

The overall objective of the investigations just described has been to obtain the most accurate up-to-date land use by the least expensive methods to determine spatial variations in water demand. The use of

remote sensing has long been employed to determine land use, but generally the remote sensing data have only been obtained by low level aircraft flights. In order to demonstrate the applicability of high altitude sensors (i.e. U-2) for land use data acquisition, a test site was selected in which a major land use mapping effort was carried out, utilizing NASA high altitude data sources. The purposes of this effort was not only to map the land use but also to systematically organize the information so that areas could easily be calculated, a variety of maps could be drawn and the data base easily updated from subsequent imagery. Preliminary findings show that a single high-altitude (NASA U-2 image can replace many low altitude images and yield far less distortion while permitting much faster data reduction to determine water demands in the Upper Santa Ana Drainage Basin.

4.1.1.2 Location and Physical Factors

The Upper Santa Ana River Drainage Basin lies east of Los Angeles (Figure 4.1) and is separated from the coastal Los Angeles Basin by the northern extent of the Santa Ana Mountains and by the Chino-San Jose Hills which rise to the west of the Elsinore Fault zone. The only river outlet of the basin is the Santa Ana River which flows through the gap separating the Santa Ana Mountains from the Chino Hills. The Elsinore Fault cuts across the upstream entrance of Santa Ana Canyon with the west side of the fault block rising nearly to the surface where it forms a barrier to underground water flow. Thus all underground water is stored or flows to the surface. At this site the Corp of Engineers has built the Prado Flood Control Dam which permits only regulated surface water to continue downstream to Orange County. At the southern end of the upper Santa Ana River Basin, between the Elsinore though on the west and the San Jacinto Fault on the east, lies the Perris fault which effectively blocks the drainage of any surface water to the south. The north and east sides of the basin are divided into the San Gabriel, San Bernardino, San Jacinto, and Santa Rosa Mountain water sheds. The mean annual rainfall increases from 28 cm (11 inches) in the southwest portion of the basin to over 38 cm (15 inches) along the foothills in the northeast area. The effective precipitation (annual precipitation minus evapotranspiration) in this semi-arid basin which has a 17° C (63°F) mean annual temperature is only 7.6 cm (3 inches).

4.1.1.3 Water Rights and Historical Demand

A series of litigations over the past 25 years between the lower basin (Orange County) and the upper basin (Riverside and San Bernardino Counties) users has resulted in a limit in the quantity of surface runoff water that may be impounded by the upper basin users. Consequently, upper basin users are not permitted to use all of the 32,824 hectare-meters (266,000 acre-feet) that is generally available annually. The water demand in the Upper Santa Ana River Drainage Basin has been greater than the local supply since the early 1940's. Imported water from the Colorado River was first delivered in 1943, with the quantity imported increasing each year. Yet, the basin has continued to be overdrafted

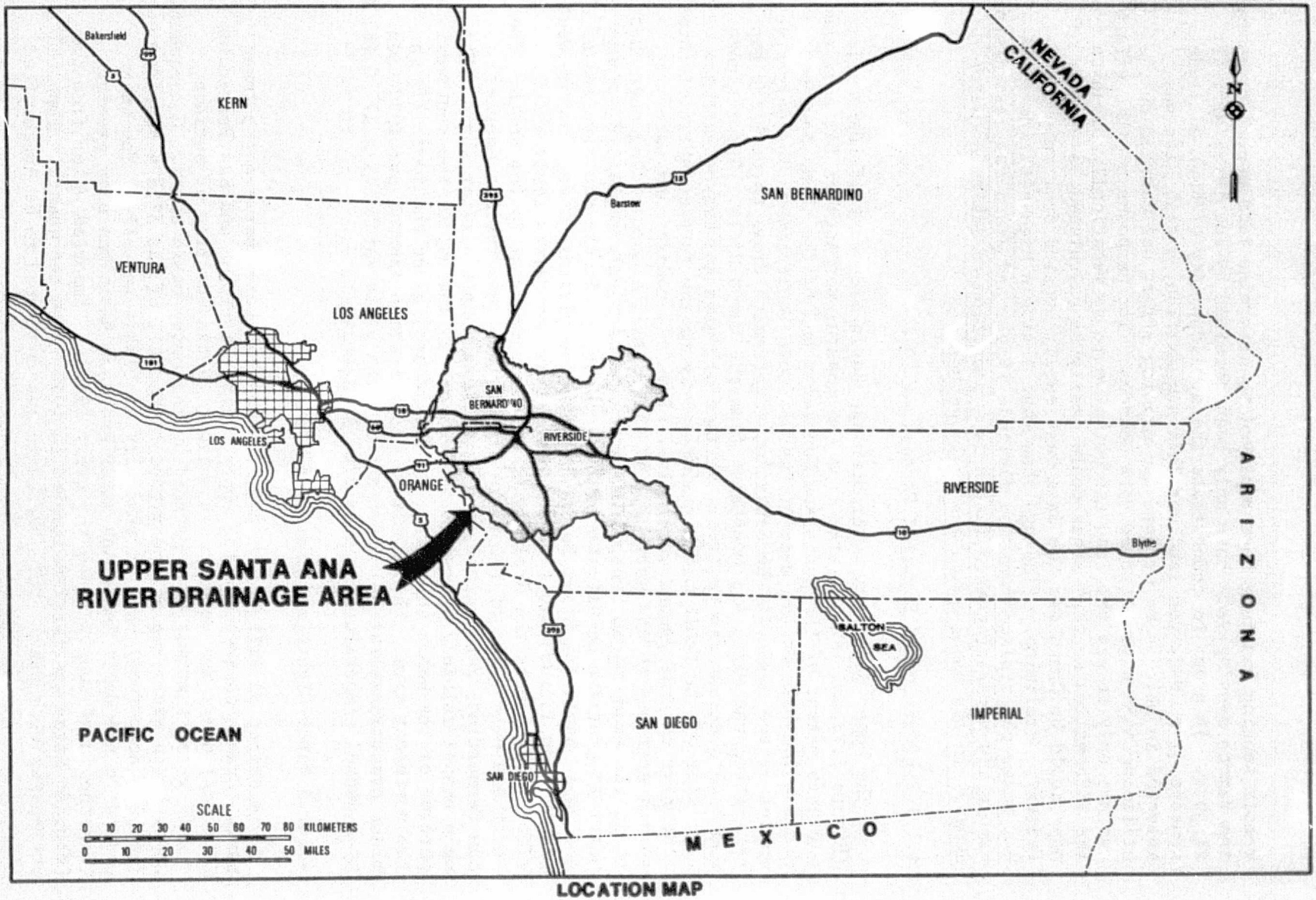

Figure 4.1 Map showing location of the Upper Santa Ana River Drainage Area

due to increased urban demands and a decreasing available supply from local surface and underground basins resulting from the above litigations. Recent deliveries from the California State Water Project from the Feather River have now been added to the system. But even this new source of water may prove to be insufficient. Since the original contract for California Project Water was made, the U.S. Supreme Court has placed a restriction on the amount of water which the State of California may draw from the Colorado River. During drought years in the Colorado River Basin this may cause a shortage of importable water.

4.1.1.4 Interaction with Public Agencies

During the past year cooperation with public agencies has increased significantly. Because of the heavy emphasis on water demand in these studies it has only been natural that the public agency of prime concern has been the State Department of Water Resources (DWR). However, the study has generated considerable interest from the Santa Ana Region State Water Quality Control Board as well as the planning departments of the two concerned counties, Riverside and San Bernardino.

Robert Smith, Senior Water and Land Use Analyst, Southern District (Los Angeles), DWR, has been in periodic contact with our U.C. Riverside (UCR) Remote Sensing scientists, exchanging ideas for improved methodologies and stating specific areas of interest of concern to his department. To assist DWR with updating their land use files of the Upper Santa Ana River Drainage Basin all land use interpretation data derived by UCR have been duplicated for the DWR. Analysts from the DWR have come to Riverside and we have cooperated in reevaluating specific areas of question and concern. As noted elsewhere in this report, the two differnet land use codes (UCR and DWR) have been cross-correlated to enable conversion from one file to the other.

Jack Newcombe, Planning Director, Riverside County and his associates have been most concerned with the development of machine-assisted techniques. In addition to cooperating in land use mapping they have been developing upon our recommendation, a machine-assisted land use system that will accommodate remote sensing data sources, including U-2 photography. The actual development of their system will be through a cooperative effort with Southern California Edison and Environmental Systems Research Institute (SRI) of Redlands. The latter group has worked closely with us in developing machine processing techniques.

Ken Topping, Planning Director, of the San Bernardino County Environmental Improvement Agency, and his associates have also been consultation with the UCR group on a periodic basis. The county has completed the acquisition of a machine-assisted land use mapping system, also in cooperation with Southern California Edison and ESRI. Ron Matyas, a former employee on this project at UCR, was hired to supervise the

implementation and coordination of machine-assisted operations in the S.B. County Planning Department.

4.1.2 Machine-Assisted Santa Ana Basin Land Use Mapping

The development and maintenance of a water demand model requires both current and accurate data for the driving parameters. The State Department of Water Resources has determined that the most reliable parameters are land use and population. Changes in long-term living habits are expressed visually by changes in land use. These changes are most discernible by means of aerial photography. Hence a unique opportunity is provided by NASA test platforms, such as the U-2 aircraft, to display their ability to provide data for solving long-term water resource problems.

4.1.2.1 Philosophy of Approach

Current staffing and equipment at the Department of Water Resources (DWR) permit the detailed inventory of a region to be made only once every decade. With the fast changing land use from rural to urban in many areas of California, DWR is forced to make long-term water supply decisions with outdated and perhaps inaccurate data. A system is needed that will provide accurate and easily updated land use information. Any system developed must be economical and attainable within the low budget of the various district offices. A statewide computer system is available to the various offices if they can prepare the data within the capabilities of the local district. The present state of data reduction within district offices is exemplified by the fact that acreage calculations are being accomplished by a careful cutting and weighing of special prints of land use maps. Hence, exotic systems that employ procedures of discriminant analysis to identify land use cannot easily be transferred to state use at this time. A system of machine-assisted land use inventory is pushing the financial limits of the local office, but can be adopted if a cost-benefit can be proved. With cooperation from the Los Angeles District office of the DWR the following outlined machine-assisted land use system is being developed utilizing high altitude (U-2) aircraft imagery for data.

4.1.2.2 Analysis of Imagery and Land Use Classification

Five high altitude aircraft (NASA U-2) missions have been flown of our Southern California Test Area, viz. the Santa Ana River Drainage Basin. The five dates of photography were December 10, 1973, March 14, 1974, June 3, 1974, October 16, 1974, and November 26, 1974 thereby covering the four seasons. The first four flights employed the RC-10 camera system using a lense with the 153 mm (6 inches) focal length and color infrared film (CIR). The 70 mm Vinton Camera package provided the

secondary sensor system. The November flight was made with an RC-10 camera and an HR-732 camera both using CIR film. On this flight, the RC-10 camera used the regular 153 mm (6 inches) lens and the other camera used a 610 mm (24 inches) focal length lens.

The 1:130,000 scale CIR imagery, as obtained with the RC-10 camera, is providing an average ground resolution of about 6 meters (20 feet). The 1:32,500 scale imagery, as obtained with the HR-732 camera, is providing ground resolution of about 1.3 meters (5 feet). This is proving sufficient to interpret land uses to better than the second level of classification (see Table 1) which is adequate to fulfill the need to determine water use categories.

Our research effort has contributed to a further understanding and definition of land use classification systems from high altitude and satellite imagery. The land use definition required for calculating water demand differs from that needed by most planners. Planners desire more detailed urban identification while water resources agencies are more concerned with unit area definition. The ideal classification system would provide sufficient definition in both urban and rural environments for all users. Therefore, the studies performed under this grant have been designed to develop a system that would provide the most accurate water demand estimate, but at the same time could be used in a machine-assisted geographic information system capable of being utilized by other type users without modification. Table 1 lists the UCR land use classification adapted to this study with the equivalent State Department of Water Resources land and water use classification shown in the adjacent column.

One of the more significant adjustments in land use interpretation from high altitude aircraft/satellite imagery is in the Living Area (Residential) category. Housing density is the more apparent residential feature rather than numbers of single buildings. Consequently, the concept of classifying living areas into low, medium, or high density classifications is introduced. The low density includes urban residential lost of 0.13 hectares (1/3 acre) or greater, rural residential on lots of 0.2 hectares (1/2 acre) or larger, and resort houses (mountain cabins or other type second home recreation house). Medium density housing is comprised of the area generally classified as separated single family dwellings on lots of less than 0.13 hectares (1/3 acre). High density living areas can often be detected as apartments of 3 or more household units, hotels, motels, and other buildings devoted to providing hhelter for multiple residents.

Industrial areas are detectable as either heavy or light. Light industries are usually of lesser acreage and found in a particular portion of urban areas according to local zoning ordinances. Some "ground truth" is usually required if differentiation between light industry and commercial

Table 1

LAND AND WATER USE CLASSIFICATIONS

UCR CLASSIFICATIONS Code	Title	DWR EQUIVALENT CLASSIFICATIONS Code	Title
1	LIVING AREA	-	RESIDENTIAL (URBAN & RECREATIONAL)
11	Medium Density Urban (Single)	UR	Urban Residential
12	High Density (Multiple Units)	UC 2/RR	Motels, Urban & Resort
		UC 4	Urban Commercial (Apts & Barracks)
14	High Density (Mobile Homes)	UR	Urban Residential
15	High Density (Transient Lodge)	UC 4	Urban Commercial
13	Low Density (Urban Estates)	UR	Urban Residential
16	Low Density (Rural Dwelling)		
17	Low Density (Recreation Unit)	RR	Recreation Residential
2-3	INDUSTRIAL (Manufacturing)		URBAN INDUSTRIAL
21-27	Light Industry	UI 1	Manufacturing
28-34	Heavy Industry	UI 61-12	Sawmills, Oil, Paper, Meat, Steel, Food
4	TRANSPORT & UTILITIES		
41	Railways & Rail Terminals	UI 3	Storage & Distribution
42	Motor Transport Facilities		
43	Aircraft Facilities		
44	Marine Craft Facilities		
45	Highways and Roads	UV 4	Urban Vacant, Paved
46	Automobile Parking	UV 4	Urban Vacant, Paved
47	Communications	UI 3	Storage & Distribution
48	Utilities (water, gas, elec. sewer)	UI 3	Storage & Distribution
5	COMMERCIAL (Trade)		URBAN COMMERCIAL
51	Wholesale Trade	UI 3	Storage & Distribution
52-58	Retail Trade	UC 1	Misc. Establishments
6	SERVICES		
61-66	Commercial & Professional	UC 1	Misc. Establishments
67	Government		
68	Education	UC 6	Schools
69	Social	UC 5	Institutions
7	CULTURAL, ENTERTAINMENT, REC		
71	Cultural	UC 7	Auditoriums, Theaters, Churches
72	Public Assemblies	UC 7	Auditoriums, Theaters, Churches
73	Amusements	UC 7	Buildings & Stands w/race tracks, etc.
74	Recreational Activities	UC 7	Football Stadiums, sports parks
75	Resorts & Camps	RT	Camp & Trailer Sites, Recreational
76	Parks and Golf Courses	P	Parks, Recreation
8	RESOURCES		
81	Agriculture	A	Agriculture
81.4	Dairies	A	
82	Agriculture Related	S	Semi-Agriculture
83	Forestry Activities		
84	Fishing		
85	Mining	UI 2	Extractive Industries
9	UNDEVELOPED		URBAN VACANT/NATIVE
91	Land	UV-1	Unpaved, Urban Vacant
92	Forest	NV	Native Vegetation
93	Water (Incl Dry Channels)	NR	Riparian Vegetation
		NW	Water Surface

wholesale trade is required. The heavy industries (oil, steel, food processing) are detectable by their larger acreage and urban fringe location.

The transportation classification, because of the linearity of features and the large overall size, can be identified to the third and even fourth level of classification, although identification was necessary only to the second level for this study. Likewise, utilities (power substantions, water plants, sewer plants, and gas facilities) are detectable to the third level from high-altitude imagery.

Commercial wholesale and retail trade is generally limited in detection to the first level of identification. Depending on location in the urban area, wholesale trade is confused with either retail trade or light industry. Second level detection of commercial trade buildings is extremely difficult unless the trade possesses some unique feature of more than 6 ground meters (20 feet) resolution.

The service classification is detectable by the distinctive features of government, educational, religious, and hospital buildings. The exceptions are business and professional services. Unless business services are uniquely located, it is difficult to distinguish them from retail trade.

Amusements and recreational activities can often be classified to the third level because of the large land area involved. Cultural buildings and public assemblies demand approximately the same water use and can be consolidated for investigation. Recreational parks, golf courses, and resorts require a similar quantity of water due to the large expanse of grass areas. They too have been consolidated, although coded separately.

Resources in the Upper Santa Ana River Drainage Basin are classified into three second level categories; Agriculture, Forestry activities, and Mining. For the first phase of study, agriculture is only being classified to the second level. The high altitude aircraft imagery taken on sequential dates provides adequate data to identify agricultural crops to the fifth level of necessary. Because of the specific investigation mentioned earlier, all dairies are being identified separately from general agriculture.

Undeveloped land is being coded to second level classifications of open land, forest, and water. Dry water channels are classified under undeveloped water even though many of the dry channels only carry runoff flood waters or underground percolation.

<u>The four date, high altitude aircraft CIR imagery, has been adequate to classify all of the land use in the Santa Ana River Drainage Basin to</u>

at least the second level, a level adequate for a water demand model that uses land use as the driving parameter. (Driving parameter is defined as the one factor in a model that if incorrect or changed in character will cause the greatest error or change in the final results produced by the model.)

4.1.2.3 Statistical Compilation of Land Use Acreage

While the production of a map is necessary to display the results and provide the planners with a better idea of where future actions should be directed, the most important result of the land use mapping for water demand studies is in the compilation of acreage statistics. Once a polygon has had its vertices identified and encoded into machine-readable form, it becomes a simple, almost instantaneous, calculation to determine the acreage of the polygon. Summaries by land use type, hydrologic sub-unit or any other pre-defined sub-division are obtainable in less than one minute of computer time on an IBM 360-50.

Thirty-two maps comprise the base map grid overlay of the Santa Ana River Basin. All maps have been interpreted and exist on mylar overlays. All of the maps have been completed to the stage of a preliminary shaded map, acreage calculations, and outline plot. These figures are shown in Table II. This essentially completes the construction of the data bank. However, final editing and special updating techniques are presently being developed. This stage of research involves the investigation of methods that rely on the combination of high altitude image sources and computer processing to produce a regional land use data base that can be kept up to date with a minimal amount of effort.

4.1.2.4 Editing and Updating Procedures

In order to facilitate the mapping of land use change in the Upper Santa Ana Basin, objectives and procedures have been formulated. The objectives were devised to insure that: 1) current and reliable land use maps are produced quickly; 2) the land use succession can be detected and measured and; 3) the operational procedures and land use classification system are compatible with the land use information system.

The procedures applied to this land use updating project are designed to eliminate the unnecessary production steps. The successive steps, as diagrammed in the flow chart, (Figure 4.2), are outlined below.

The original land use map and the digital land use outline file are readily available for each quad sheet as a result of effort prior to updating. As recent imagery suitable for updating purposes is acquired, a mylar outline of the original land use is produced by the computer at the same scale as the imagery.

Land use change is compiled directly upon the mylar overlay which has the original survey plotted on it. The land use outline is then interpreted for change. This procedure of drafting updated information upon the original map requires less production time and reduces the possibility of error during the transferring of data.

Table II -

LAND USE AREA OF THE UPPER SANTA ANA RIVER DRAINAGE BASIN, 1975

CLASSIFICATION	HECTARES	ACRES
LIVING AREA N.D. (non-differentiated)	60	148
Urban, Single Dwelling	51778	127941
Urban, Multiple Dwelling	194	479
Rural, Mixed Dwellings	1794	4433
INDUSTRIAL N.D.	2125	5252
Light	106	262
Heavy	1157	2858
TRANSPORTATION and UTILITIES N.D.	376	929
Transportation	4915	12145
Utilities	1844	4556
COMMERCIAL or TRADE N.D.	4179	10326
Wholesale	209	517
Retail	242	598
SERVICES N.D.	98	242
Business and Professional	690	1706
Government	4322	10680
Educational	3037	7505
Social	60	148
CULTURAL, AMUSEMENT and RECREATION N.D.	42	105
Cultural and Public Assembly	438	1082
Recreational, Resort and Parks	4871	12035
RESOURCES N.D.	561	1386
Agricultural	100882	249276
Forestry, Fishing and Mining	948	2343
UNDEVELOPED N.D.	2141	5292
Land	185127	457443
Forest	129036	318843
Water (including dry channels)	16054	39669
Unclassified	69332	171316
TOTALS	586,618	1,449,515

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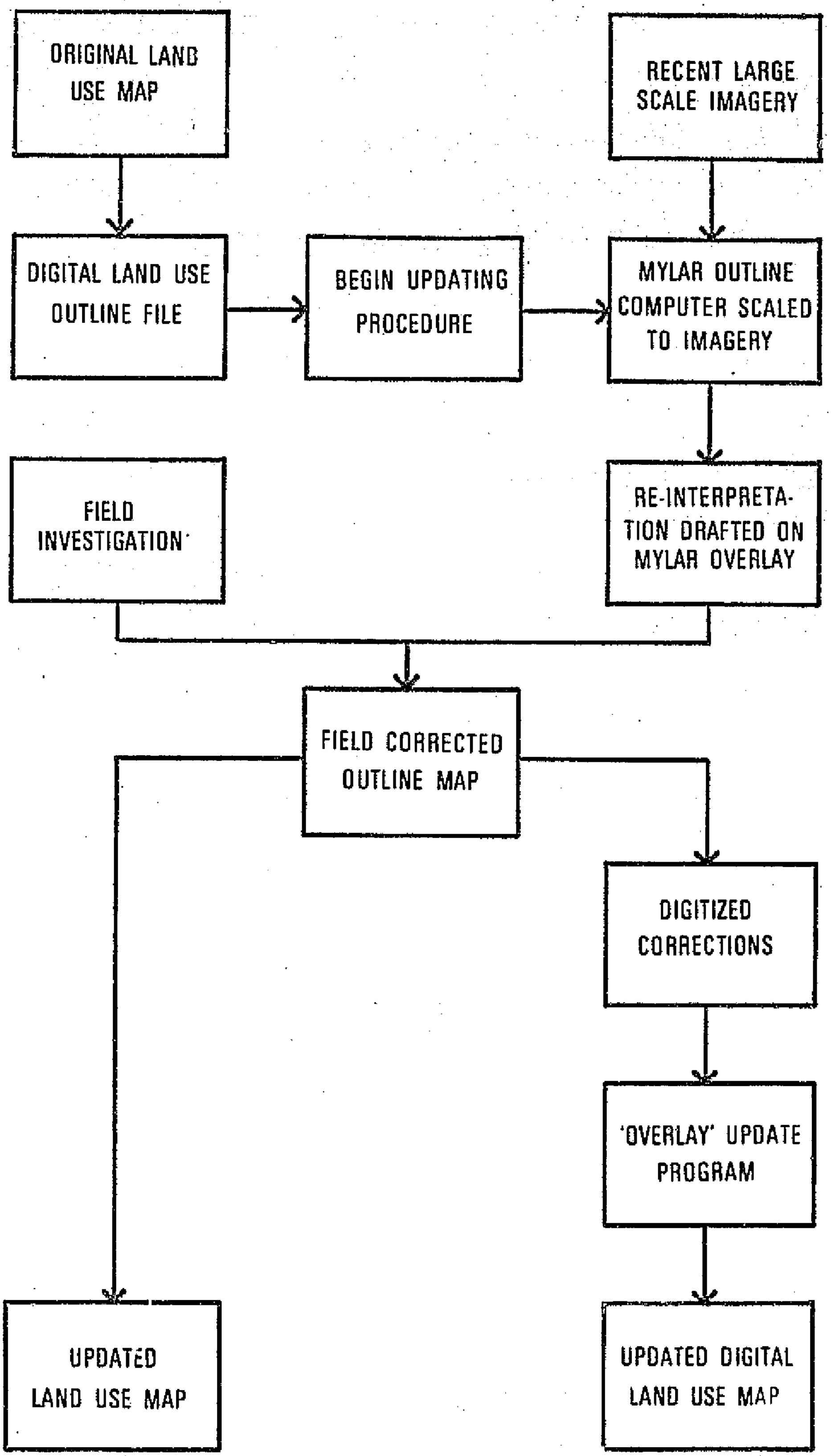


FIGURE 2. Flow chart showing procedure used in preparing updated land use maps of the Santa Ana River Drainage Basin with the aid of high altitude color infrared aerial photography.

When changes are being redrafted on the overlay, colored pencils are used so as to facilitate the detection of errors and the determination of types of changes that have occurred. The horizontal movement, in terms of the function change between the two time periods, is the primary point of interest.

Field investigation of the updated maps immediately follows the interpretation. Corrections of the map are made on the site location to reduce the error factor. An updated land use map is then produced from the field-corrected map. The updating of the digital map file, based on the changes detected by the above procedure, is the next step.

Digital map updating can be viewed as either editing, overlay, or insertion. In any case, the ease with which this updating task can be accomplished is a function of 1) the nature of the change information (i.e. functional, positional, or a combination); 2) the nature of the update data source; 3) the data structure of the map, or in other words, the manner in which the map is represented on a computer compatible storage medium; and 4) the nature of the computer configuration and operating system available to the user.

It is our philosophy regarding the latter that the development of a spatially updateable software system should be both batch and interactively oriented in order to accomplish the technology transfer function. As well it should be fully supportable under either operating environment.

Because our research efforts involve the use of remotely sensed imagery as an update data source, parameter two (above) is both constant and a given. The use of imagery for digital map updating leads to a situation where all updates can be known and mapped at a particular time. It is therefore desirable to be able to execute the digital map update in a single operation.

The nature of the change information is complex, being both positional and functional, and requires that positional accuracy standards be observed by digitizing boundary changes. Most information systems satisfy data input requirements by either interactive sessions with sophisticated interactive digitizing devices (essentially a special edit operation) or (in batch operations) by inserting all boundaries of all affected polygons, a procedure which requires much redundant data input. Normally only one of these operations is available to the system use, dependent upon his computing environment, and is restrictive due to inflexible data structures.

Software research and development activities are underway, addressed specifically to single-run updating from imagery sources in either batch or interactive modes, and not requiring any equipment more sophisticated than an off-line digitizer and interactive terminal. These activities are presently oriented toward creating and testing a data structure which will allow the flexibilities and unique data input described above. Presently it is felt that a directed, topologically-linked data structure will provide the necessary flexibility as well as negate redundant data entry. Low level subroutines are being written which will accomplish the maintenance

of the data structure. In addition these subroutines provide the basis for a complete spatial information processing/operating system uniquely suited to remotely sensed data inputs.

4.1.2.5 Preliminary Cost-Benefit Estimates

Although a strict comparison of DWR and UCR methodologies is impossible due to a difference in products and system flexibility, the following observations can be made:

a. Initial map preparation and conversion to machine code requires about .13 man hours per polygon (an average map in this study has 190 polygons) or approximately 25 hours per map. Average plotting and computer processing costs amount to about $140 per map. It is felt that these figures represent the same time/cost factor as that required for manual land use data conpilation. The figures do not include data gathering, where remote sensing far exceeds ground survey methods in efficiency.

b. Cost-benefits begin to apply when (once in machine form) the data are: 1) analyzed; 2) cross correlated with other data; 3) used to produce statistics such as acreages or population densities, and/or; 4) used to produce maps with various scales and shadings. For example, acreage calculations are essentially "free" at this point.

c. Cost-benefits will be greatly increased when updating and editing procedures are performed. Preliminary studies indicate that approximately 20 man-hours will provide machine input data for a map update where normal manual updating procedures are likely to require upwards of 200 hours. For this one study area alone such savings should be multiplied by 30 maps, giving a total savings of 5400 man hours.

d. The interest by DWR was not only in our study of the machine assisted processes, but also in determining what is the relative cost in hardware to place each district into operation on a machine-assisted basis. The minimum starting cost for hardware was found to be $15,000.

4.1.3 Population Studies

Water demand can be divided basically into urban and agricultural components. For estimating present water consumption, DWR utilizes population data and water delivery data for service districts to arrive at a per capita water use statistic. Over time, these statistics yield water consumption trends which may then be used to extrapolate future water demand. This technique cannot be applied to agricultural water use because population has no relevance. For purposes of urban water demand estimation, however, this procedure is proving quite useful, even though it has limitations for some planning purposes because of the aggregated nature of the data.

4.1.3.1 Urban Per Capita Water Demand Estimation

The method currently being used in estimating urban per capita water use consists of a set of procedures which establishes a gallons-per capita-per day (gpcd) figure for urban and industrial water uses in each water

service district. The applicability of this method is limited to those service districts where reliable population and delivery estimates are available. Procedures employed by DWR are. 1) Annual Deliveries are calculated; these include metered municipal and industrial use plus system losses minus agricultural use and water sold to other utilities; 2) Population for a given year is calculated by deriving, from census data, persons per water service connection and/or persons per dwelling unit, which is interpolated between census years and multiplied by the number of water service accounts or dwelling units. Where census data are not available, population estimates are provided by the water agency itself. Therefore, annual water production in terms of gpcd is given by the following equation:

$$gpcd = \frac{\text{Annual Production (gal/yr)}}{\text{Population}} \times \frac{1}{\text{days/yr.}}$$

Straightaway one may see that the above procedure relies heavily on population data and/or dwelling unit counts for accurate estimates. On the whole, DWR analysts feel that intercensal population estimates, which are made by the State Department of Finance, cities themselves, and water service districts on a "new connections" basis, are adequate for most highly aggregated long-term projections. However, these analysts have expressed a need for knowing where this population exists so that proper estimates can be made in the context of DWR's hydrological sub-unit planning areas, as well as other arbitrary aggregation units. In order to obtain such information, the spatial patterns of population must be established, preferably through the use of remote sensing techniques.

4.1.3.2 Disaggregation of Population Using Remote Sensing

One study currently in progress addresses the need to analyze water use on a per capita basis. This study demonstrates the combination of data from the decennial census and high-altitude color infrared imagery. At least one value of this combination of data is the amplification of its geographic component. For example, it would be useful to show not only the extent of each census tract, and its population aggregate, but the actual area within each census tract that is occupied by various forms of land use. The use of high speed computers and readily available software, coupled with remotely sensed land use patterns, allows rapid and accurate calculation of land area used versus land not used. In addition, the enumeration of areas occupied by any of several land uses can be accomplished efficiently and may be delivered in a per capital format.

Population density has been calculated by using a combination of census data and imagery for a sample portion of the San Bernardino area -- which is within the Santa Ana River Drainage Basin. The sample study involved the interpretation of the areas of residential land use from high altitude CIR imagery (Figure 4.3). The residential pattern for each census tract was then converted into a computer-compatible format by digitizing the polygon boundaries for residential and non-residential areas for the entire study area. An automated mapping program (CHROMAP) was then used to produce both

the map (Figure 4.4) and the area calculations for each census tract, and for each contiguous residential area within that tract. The residential area was then used instead of the census tract area to calculate residential population density within that census tract. The advantage gained is that the actual areal location of water demand is now known. The locational per capita data can be updated periodically by comparison of the mapped patterns with more recent imagery to check for changes in the residential pattern. Then, by applying density figures to changes areas, a new population estimate can be made.

By making a few assumptions about population dynamics, one can depict the changes in population for a small area in both positive and negative amounts. The first assumption is that the per dwelling unit population density within a census tract will not change rapidly. The second assumption is that the population is proportionately divided into the residential land use polygons of a particular census tract. The utility of these assumptions is that, by defining a density population statistic, the total population of any planning unit, (i.e. hydrologic subunit, fire district, school district, etc.) can be obtained by summing the population of all of the residential areas contained within that planning unit. For residential areas which are split by planning area boundaries the per capita density figure will reveal the expected number of persons in that part of the residential unit occurring within the planning area, -- information which can only be estimated relative to area. As an added benefit, intercensal population can be estimated by simply evaluating an image of the area taken at the time in question and by applying the old population density to the more recent polygon configuration. Care must be taken to insure that areas which are no longer residential, or areas of vacant housing, are subtracted and that new areas of residential land use are added. (This can be done either manually or with a computer polygon overlay system.)

The unique element of this procedure is that it is sensitive to population migration. In areas of doubt, ground truth is required to determine the exact nature of the change within a residential area.

4.1.4 Special Investigations of Agricultural Land Use

4.1.4.1 Identification of Special Crops-Citrus

In order to establish trends in water demand for agriculture it is necessary to intensively study the trends associated with each crop type. As a demonstration of the use of remote sensing for crop type trend analysis in the Santa Ana River Basin, citrus was chosen because of its regionally significant consumption of land and water resources. At present, citrus is the most extensive single agricultural land use type in the Upper Santa Ana River Basin. It is also a perrenial crop and requires irrigation through at least three seasons. In 1964 citrus occupied approximately one-third of all producing crop land in the basin (50,000 acres; 20,236 hectares) and required about 75,000 acre feet (9,255 hectare meters) annually of irrigation water.

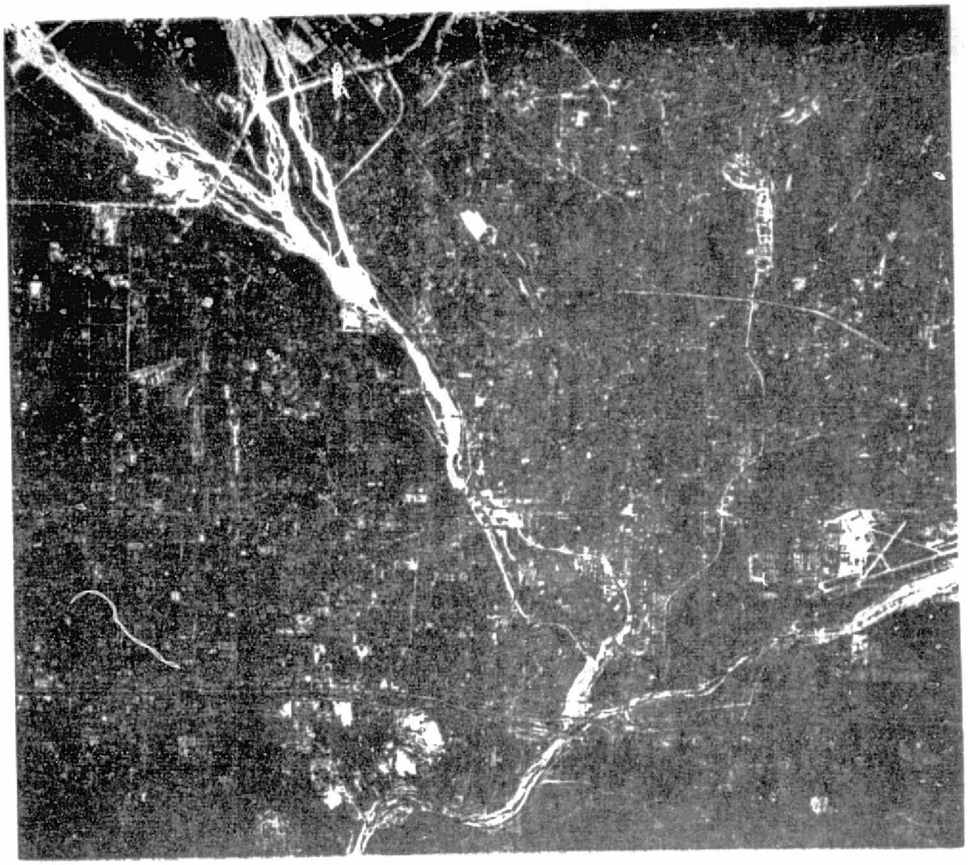


Figure 4-3 . Black-and-white reproduction made from a CIR original photo of San Bernardino, California showing actual living areas as outlined in Figure 4 and overlayed on the 1970 census map. (NASA-Ames U-2 photo November 8, 1974, Nominal scale 1:130,000).

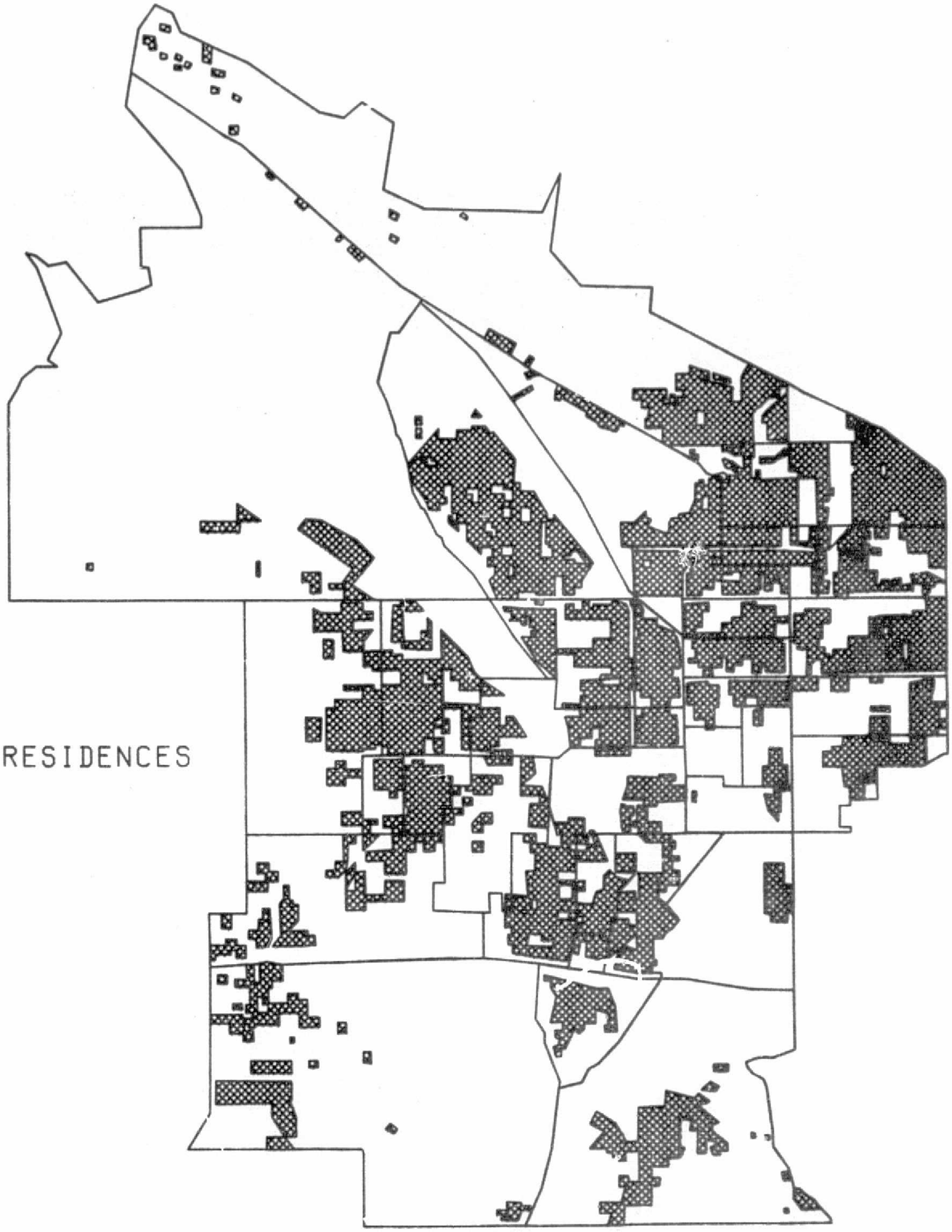


Figure 4.4. Shaded computer map of living (residential) areas of San Bernardino, California, showing the specific areas of population as contrasted to population normally displayed as covering entire census tracts.

It has been speculated that the increase in urban activity in the basin has led to a regional displacement of the citrus crop to the San Joaquin Valley. Although it is visually apparent that citrus is being preempted by urban and suburban land uses it is not so apparent that the crop is leaving the region. In fact, citrus is moving from the urban fringe areas into the plateau area in the vicinity of Lake Matthews and into the low foothills and alluvial fans of the northeast slope of the Santa Ana Mountains.

Projection of long-term water demand for the basin requires that the citrus crop be monitored. The use of remote sensing techniques is known to be efficacious for surveying agricultural patterns. High altitude image sources offer advantages of speed and accuracy as well as an intensive and extensive view of land utilization. A comparison of imagery at different times can show either an increase or decrease in any given type of land use (e.g. citrus) and also the direction and rate of significant migrations. Certain characteristics of citrus make it a particularly easy form of land use to survey using high altitude imagery. A subtropical tree crop, the evergreen citrus is easily distinguished from deciduous tree crops during their dormant season. Certain climatic and soil requirements combine with economic factors to concentrate citrus in relatively homogeneous areas. The regular shape of the citrus crown makes it readily distinguishable from the two other subtropical crops with which it could otherwise be confused, -- olives and avocados.

Temporal and spatial trend analysis of the citrus crop commenced with the establishment of a base time period and a recent time period in which changes could be detected. The time between the surveys needed to be long enough to reflect the urban growth influence on a permanent crop. Black-and-white photo mosaics of portions of Riverside (1959) and San Bernardino (1961) Counties provided a base period at the time when urban sprawl was beginning. NASA U-2 imagery at a scale of 1:130,000, flown on two dates (October 16 and December 10, 1974) was used for a survey of the present pattern. Areas of citrus were outlined on reference maps made from USGS 15' Quadrangles. Maps of the two time periods were then combined, digitized and processed to obtain area statistics and establish a locational base for future investigations. Imagery of the Ontario-Pomona area is illustrated in Figure 4.5. Figure 4.6 is a final map showing the various change patterns. The Ontario-Pomona area contains much urban fringe and (as presumed) the map reveals a decrease. This decrease amounts to 8303 acres (3360 hectares) between 1959 and 1974. This procedure is presently being carried out for the relevant areas of the entire basin. Table III gives a statistical account of maps presently completed.

4.1.4.2 Estimation of the Inactive Field Period

The presence of absence of irrigated agriculture in a particular region represents information which is very important in DWR water demand estimation models. In Southern California, multiple cropping practices give rise to a condition in which the use of a single sample to estimate irrigated agricultural lands may lead to an erroneous estimate. Remote sensing, with its rapid inventorying and synoptic sampling characteristics, enables the use of multiple samples. If these aerial samples are taken at selected times throughout the year, a more accurate annual average of irrigated

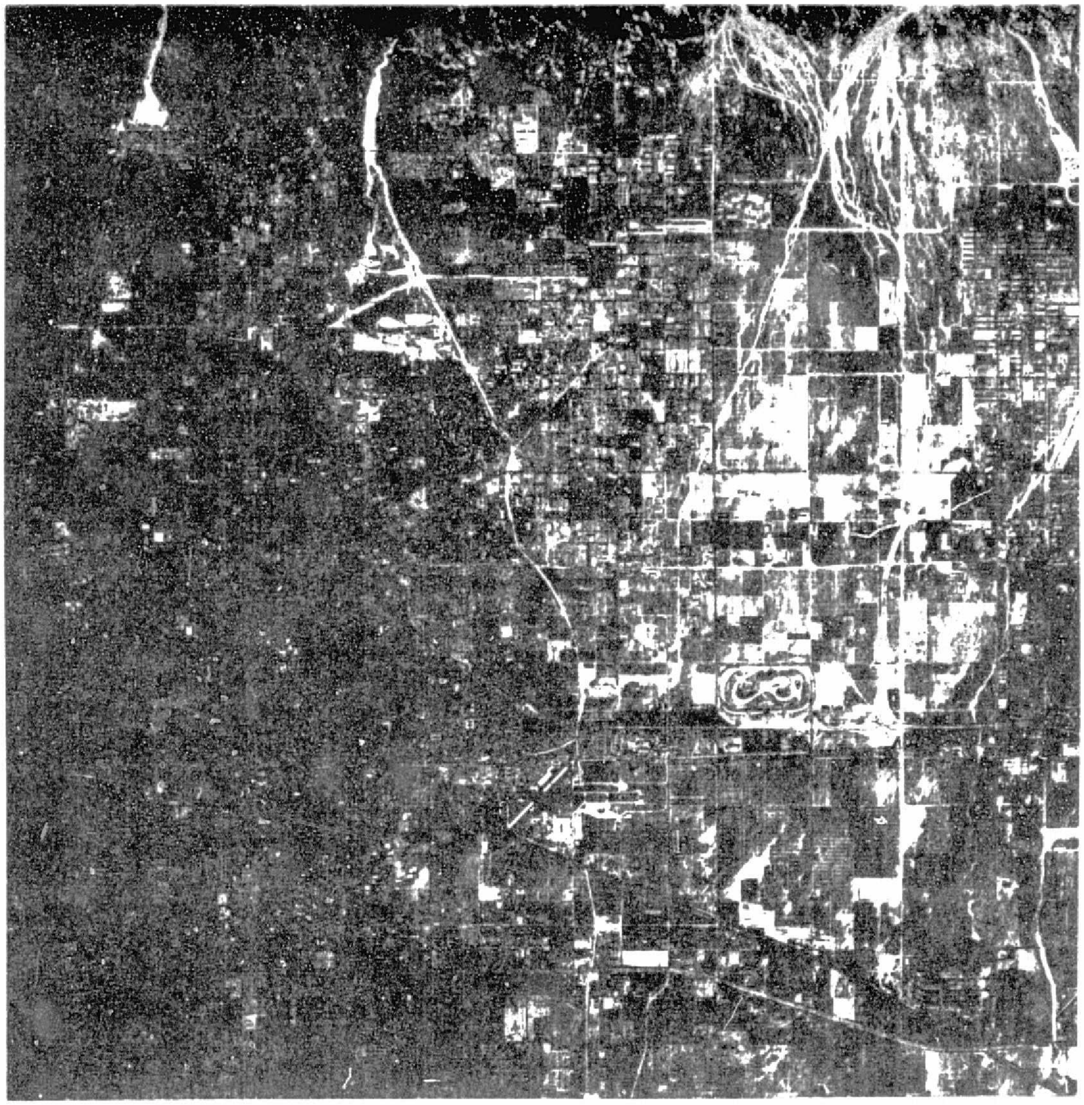


Figure 4.5. Black-and-white photo of an original CIR image of the Ontario-Fontana area, California. The black fields in the upper left show the remaining citrus groves in Upland, California. The few remaining citrus groves in Fontana are in the upper right high up on the Cucamunga Fan. (NASA-Ames U-2 photo November 8, 1974. Nominal scale 1:130,000).

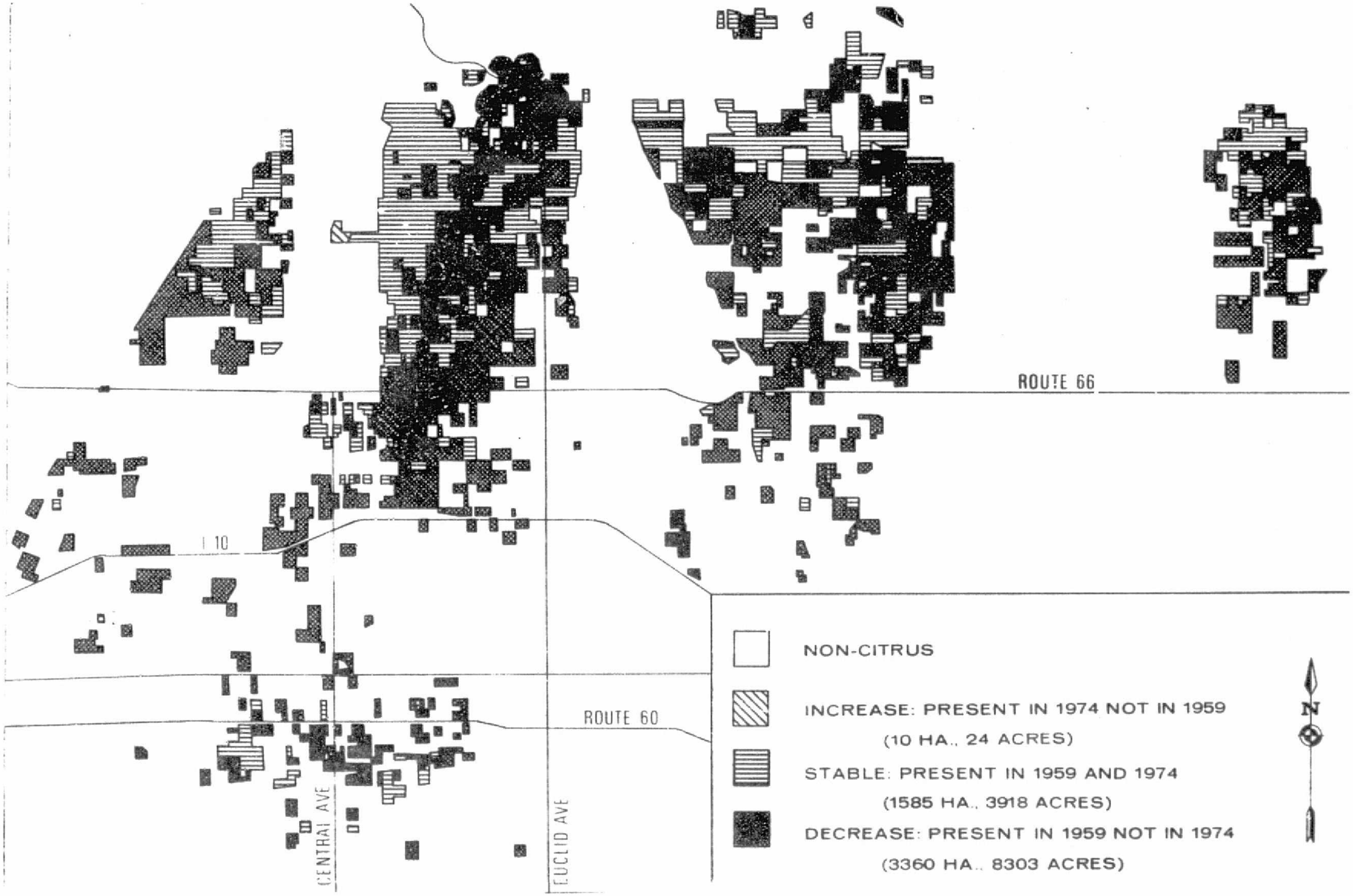


Figure 4.6 . Shaded computer map showning the change in citrus production within the Ontario-Fontana, California area.

Table III

Citrus Area and Associated Changes for completed Quadrangles

Quadrangle	1959-total ha.	1959-total acre	1974-total ha.	1974-total acre	Stable ha.	Stable acre	Increase ha.	Increase acre	Decrease ha.	Decrease acre
Ontario	4945	12221	1595	3942	1585	3918	10	24	3360	8303
Perris	496	1226	501	1239	336	831	165	408	160	396
Banning	52	129	23	58	23	58	-	-	29	71
Murrieta	-	-	18	44	-	-	18	44	-	-
Elsinore	265	653	494	1220	168	414	326	806	97	239
Totals	5758	14229	2631	6503	2112	5221	519	1282	3646	9009

Net loss = 3127 ha. (7727 acres)

Stable - present in both 1959-61 and 1974
Increase - only present in 1974
Decrease = only present in 1959-61

suffering from deterioration of their beaches. The study of beach cusps, which show up extremely well on high altitude imagery, may lead to a much better understanding of the reasons why some of the south coast beaches have an overabundance of sand, while other beaches have been almost denuded of sand. This study is merely the initial step in a farther ranging and more serious environmental study. It has been suggested by researchers at Scripps Oceanographic Institute (part of our University of California system) that the major cause of beach erosion has been the damming of upstream rivers for purposes of flood control thereby reducing the availability of new beach sands. Such damming may also constitute the reason why many of the coastal lagoons along the Ria shoreline* of Southern California have died or are dying. Therefore, <u>two primary objectives of our study on the relation of storage, damming, control and use of local and imported water are (1) to determine the impacts that deminuate coastal lagoons and (2) to evaluate the far reaching environmental effects. Any truly integrated remote sensing study of California's water resources should not overlook these important considerations.</u>

4.2.2 Malibu Corridor Traffic and Recreational Use Study

4.2.2.1 Background

The established usefulness of U-2 imagery for land use-based studies (cit. the Upper Santa Ana River Basin study) initiated an investigation into the suitability of this imagery as an aid in the development of a simulation model for the analysis of activity change in a coastal area. The purpose that was envisaged for this model is twofold: first, by selection of appropriate data retrievable from the imagery, a parameterized coastal interaction zone might be developed. It is proposed that this model include (but not necessarily be restricted to) land use aspects associated with areas devoted, respectively, to housing, commercial and industrial use, transportation, and recreation. Secondly, from the land use data, analysis of subsequent imagery, and other data sources, proposed activity changes (e.g. specific land use, transportation corridors, recreation facilities) might be analyzed to project possible impact within the established coastal interaction zone.

Prime concern in our efforts to analyze project feasibility has been avoidance of duplication by governmental agencies and/or other grant or contract activities within these or similar general stated objectives. Although, literature survey and contact with several governmental agencies within southern California revealed that there is activity in this general area, in no instance was a remote sensing-based model for making a comprehensive study of changes in coastal zone activity either perceived or in progress. Some related activity was found at different California governmental levels or in conjunction with with the University of California Sea Grant Program (NOAA Grant #USDC 04-3-158-22). Governmental interests and activities include ongoing monitoring of coastal land development by the California State Coastal Zone Commission; and a study by several agencies of extra-community transportation user needs in the Los Angeles area along California State Highway 1 (the Pacific Coast Highway). The specific

*Ria shoreline is defined as one formed by partial submergence of an area which was previously dissected by subaerial erosion.

agriculture, or conversely of inactive fields, can be obtained.

Research involving estimation of inactive fields is being directed toward: 1) defining the most appropriate time of year for overflights; and 2) defining and evaluating interpretive signatures for high altitude and satellite imagery. A study area situation in the Perris-Moreno Valley is presently being analyzed. The study area was chosen because of representative mixes of various types of agriculture. Irrigated-inactive field samples are being made from CIR high altitude U-2 imagery of: (1) December 10, 1973; 2) March 14, 1974; 3) June 3, 1974; 4) October 16, 1974; and 5) November 26, 1974.

4.2 Studies in Remote Sensing of the Southern California Coastal Environment

4.2.1 Introduction

In our Annual Report of May, 1975 we proposed that a portion of our research this year would consist of studies involving the coastal area of southern California. Two areas of study have evolved from this proposal: 1) studies relating to environmental impacts of human activity within the coastal zone, and 2) studies relating to the physical features of the coastal zone which are being modified by human interference with the natural processes.

The primary objective of the proposed research in the coastal areas has been to seek out problems of concern to public agencies and then determine the extent to which remote sensing can provide data that will assist in the solution of such problems.

As will be discussed in the next section the first study project undertaken was requested by transportation planners of various public agencies in southern California. The problem, which results from an abundance of human activity in the Los Angeles basin, has been perceived by the residents of the Malibu Coastline area as that of traffic congestion. Several phases of study have been performed by various agencies at several levels of effort. One phase that had not previously been investigated which constitutes an objective for part of our study is that of determining the extent to which remote sensing facilitates the analysis of traffic congestion resulting from recreational activity in an intensively used area. This phase of our study used as a test site the Malibu corridor.

Some preliminary results of the study indicate that the problem of traffic congestion in this particular area may not be a real as the residents perceive, but this initial impression may be due to both the dates and the times of day selected for the two imaging flights that have furnished us with initial data.

The second area of study, dealing with coastal processes, is just in the planning phases. A minor study (the study plan for which is detailed in the next section) is concerned with the morphology of beach cusps and addresses part of the major problem of beach sand erosion. Several communities in the south coast beach areas, especially Newport Beach and Oceanside, are

relevant project within the Sea Grant Program is an effort to establish a simulation model of coastal zone land use change, using the community and environs of Santa Cruz, California as a test site. This project, however, is based on data sources other than remotely sensed imagery.

Inquiries directed to involved governmental agencies proved our proposal to be generally positive in relation to their requirements. The need for a standardized data base was perceived as foremost in the coordination and integration of efforts at all levels. For example, perceived requirements by the California State Coastal Zone Commission did not include any positive action, predictive impact methods. Interest was expressed only in determining what monitoring capabilities might reside in available imagery for the detection of unauthorized coastal land development. Although possible, this type of police action is not deemed congruent with our active NASA-funded research efforts.

More definite interest was stated in proposed project capabilities by the following agencies:

The California State Department of Transportation (Caltrans)

The Southern California Association of Governments (SCAG)

The Los Angeles County Department of Roads

The City of Los Angeles Planning Department

The City of Santa Monica Planning Department

A common objective of these agencies is to determine the basis of perceived chronic traffic congestion along the Pacific Coast Highway from the McClure Tunnel at the western terminus of the Santa Monica Freeway in Santa Monica through the residential community of Malibu (the Malibu Corridor), entitled "Routes 1 and 64 Transportation Study". Included is a desire to determine the effect, as a contributor to this congestion, of recreation activities at adjacent beaches in the area. The specific research plan, developed by our UCR group in conjunction with these agencies entails investigating and analyzing the impact of recreation and related transportation activity, based on available remote sensing imagery within the limits of our study area. This proposal was readily endorsed by these various agencies because they felt that this is an important part of the traffic flow problem. In conjunction with this, efforts have been directed by our UCR remote sensing scientists to beach use (available recreation area acpacity as opposed to actual use) and correlated parking facility availability. The general approach entailed in our efforts to maximize the usefulness of remote sensing in connection with this Malibu Corridor Traffic and Recreational Use Study is as follows:

a. Establishment of individual beach morphology

1) water frontage

2) associated depth to parking access or roadways

b. Establishment of parking availability for each of the defined beach areas

   1) on-site private and public parking lots

   2) free roadside parking

   3) feeder street parking

c. Establishment of the number of beach users for particular beaches

   1) nodes of activity

   2) investigation of "under" and "over" used beaches

   3) stablishment of beach personality

      a) Number of users as a function of:

         (1) beach area available

         (2) number of vehicles noted in parking areas

d. Relation of observed densities to:

   1) availability of facilities

      a) lifeguard service

      b) refreshment stands

      c) rest rooms and bath houses

      d) other amenities (e.g. bike paths, children's play areas, fire pits and etc.)

   2) proximity to heavily populated residential areas

   3) perceived area traffic congestion problems.

Figure 4.7 illustrates the great potential of aerial photography in satisfying several of the above-listed informational requirements.

4.2.2.2 Current Studies

Activity has centered on four phases of the transportation study: 1) on-site survey of the study area 2) completion of a locally-contracted, low-level mission to establish ground truthing methods 3) analysis of the summer season high level photography (NASA mission #75-144) and 4) commencement of methods development and analysis. The on-site survey of the study area was completed during the summer of 1975. Familiarization with beach location,

facilities and recreation, adjacent traffic arteries, and economic activities provided an insight to possible data to be interrupted from the imagery. On-site activity also accompanied the low level air truth mission. Efforts in conjunction with the mission were directed toward a license plate survey in selected parking areas to establish possible ethnic and economic level characteristics of various clusters of beach users, and to obtain hand-held oblique photographic (35 millimeter slides) of selected sites from favorable vantage points for use in connection with projected beach user censuses. A selected beach site was again photographed as above at the time of the summer season high level mission (NASA mission #75-144) for the same purpose.

Preparation of vehicle license plate numbers for submission to the California State Department of Motor Vehicles has been completed. Geographic origin (city or area) of beach users will be provided by this department to establish the validity of ethnic or economic level composition of different beach site users.

At present, efforts have centered on the development of methods applications to a single test site within the study area. To date, experimentation to develop site morphology from remotely sensed imagery is in progress. Site morphology, including a lateral depth-water frontage beach area ratio, will provide input for assessment of the ratio between available beach area and used beach area. Several approaches are being considered. The current approach is to work from a larger scale to a smaller scale: that is, initial plotting from maps with subsequent plotting from maps with subsequent plotting directly from imagery. The Santa Monica Beach test site has been plotted from Los Angeles County Road Department maps of the Pacific Coast Highway at a scale of 1:2,400. The maps provide a ready means for establishing the political boundaries of the beaches, which coincide with city and county limits. They are a method of establishing the landward limits of each beach site. However, seaward limits, e.g. the strandline, can only be realistically plotted from remotely sensed imagery. Overall, both landward and seaward limits are easier to establish from remotely sensed imagery.

Methods are being developed and tested for identifying clusters of beach users and clusters of parked vehicles in order to ascertain number of beach users per vehicle. At present, beach clusters are recorded as to location on the beach and proximity to parking areas. Individual beach user counts are made using a mylar grid overlay with cells equivalent to 100 feet square. The adequacy of this procedure has not yet been proved. A silver-masking photographic technique is to be tested for this purpose. If feasible, future census counts will be made either by a color enhancement or a densitometric method.

The relation of observed densities to available facilities, proximity to residential areas and the perceived traffic congestion problems, will be investigated upon development and selection of adequate methods for the above inputs. Project efforts are designed, then, to establish a method based on remote sensing, for analyzing the rate of beach use and the potential beach capacity, using the above-mentioned criteria. The specific requirements

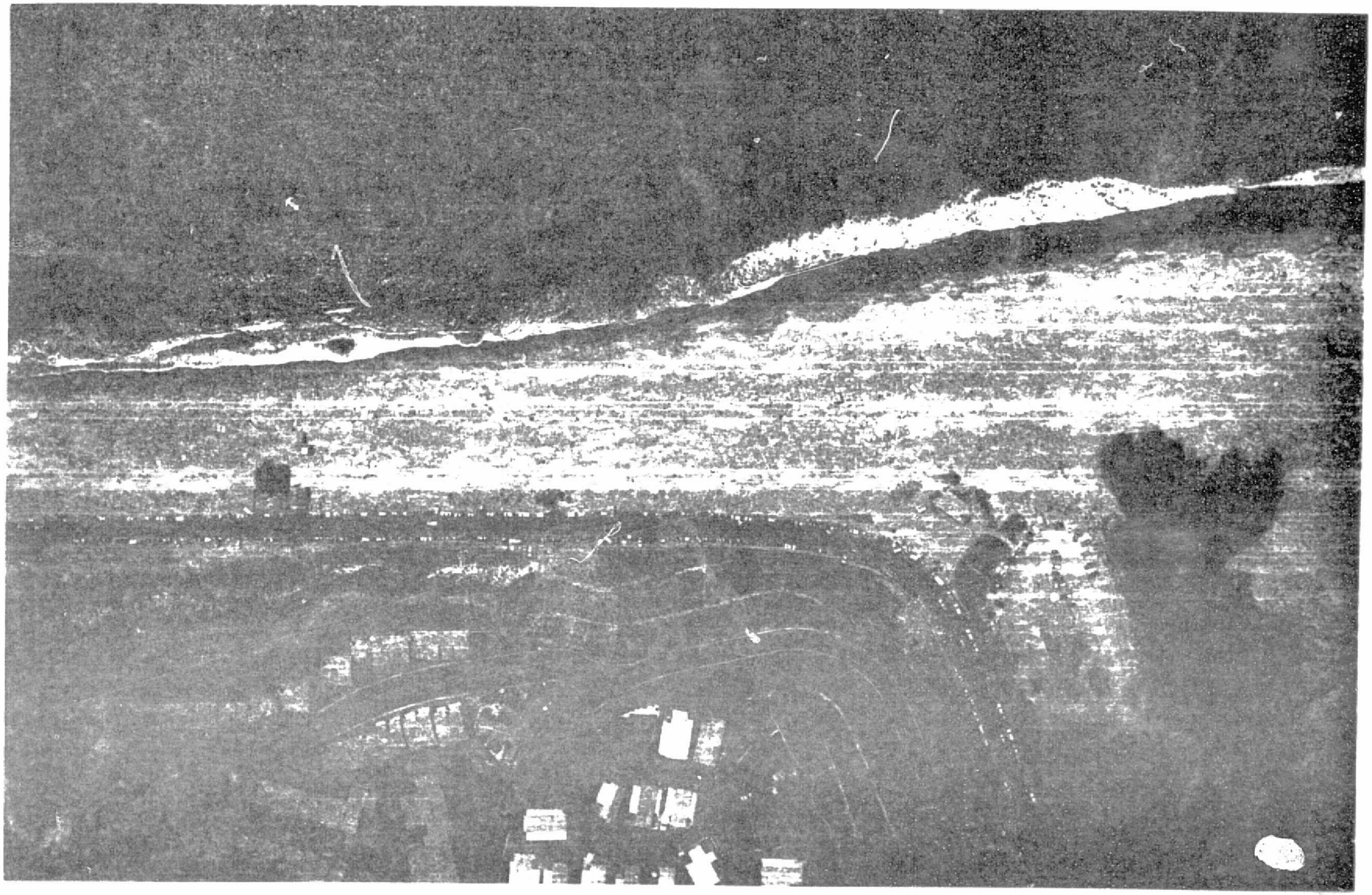


Figure 4.7. Typical clustering of beach users along the southern California coast. The scene is Westward beach at the Pt Dume, California area. The clustering is attributable to several factors including age and type of crowd, facilities, and available free on-streat parking. The beach capacity far exceeds the parking capacity. (Western Aerial Survey photo August 17, 1975 (Sunday. Scale 1:3,000)

of the Routes 1 and 64 Transportation Study are being considered in this study. In addition, the possible input of such remote sensing-derived data into a coastal zone, activity change simulation model is being investigated.

4.2.3 Applications of Remote Sensing to Morphological Analysis of Beach Cusps

The nature of sediment transport and erosion along the littoral zone has been studied widely in the past. Few of these studies, however, offer interpretive analysis of the geomorphic forms which are directly related to the sediment transport processes. One such landform is the beach cusp. The cusp is generally absent in most coastal geomorphology textbooks. The rare cases of cusp discussion center principally on qualitative description of form and shape. Reliable theory as to cusp origin is lacking and there has been very little previous analysis of cusp morphometry. Consequently, process cannot be linked accurately to form. Few valid statements concerning the expectation of the many interrelated variables controlling cusp shape and genesis have been brought forth in the literature. Remote sensing may offer the tool necessary to locate beach cusps and to allow varying degrees of inspection. Not only may high altitude photos portray the orientation of the coastline at which they occur; in addition, other appropriate scales of imagery may be found suitable for direct morphometric measurements.

4.2.3.1 Study Area

Recent field check along the Southern California coast verified our preliminary location of beach cusps based on our interpretation of remote sensing imagery. Both scales of 1:32,500 and 1:130,000 clearly revealed cusp location (Figure 4.8). Cusps are relatively isolated features, however, and their strikingly symmetric appearance offers rapid and precise identification.

A variety of locations along coastal southern California revealed cusp clusters. One of the most pronounced sections in terms of actual numbers and development of the typical cusp form was along the southern extreme of the Newport Beach split. There, form seems to be amplified by the orthogonal compaction induced by the harbor jetty, an area which is better known, especially to surfers, as "The Wedge". Because these forms may be expected to be enhanced by the nature of the spit and jetty, they serve perhaps as anomalitic forms; yet they are well developed. Further south along the coast, approximately 4 km. south of The Wedge, another longer yet less developed group of field cusps can be found. There appears to be no direct outside influence on this group so, through comparative analysis of each section, we may gain insight into their form and find the causal relationship of restrictive wave patterns. In addition, the above area is used by local inhabitants and represents some of the finest stretch of beach along the coast. It is only reasonable to study this area if any conclusions as to the many controlling variables interacting to form the cusps may prove essential in future attempts to preserve beach property. The area is readily accessible to field survey.

4.2.3.2 Experimental Design

As previously mentioned, there has been little attempt to determine beach cusp origin. Thus, the study will be approached a posteriori, as expected relationships between the many probable controlling factors are tenuous. A priori modeling is fruitless at this stage as one must have some expectation as to variable interrelationships before such an approach is viable. A reasonable approach is one requiring that a variety of morphometric parameters be measured in both fields. This will serve three functions: 1) find the relation between each variable within one set of cusps; 2) compare findings of one field to those of the other; and 3) because coverage is complete in four seasonal time periods, comparison of form from one season to another may reveal seasonal fluctuations and could supply inference to wave controls, berch erosion and other environmental impacts.

The measurements will be of three types designed to determine geometries of form, particle size distributions, and wave characteristics, respectively. The following parameters listed in table IV are considered desirable. Most of the measurements are possible from the 1:32,500 scale. Of course an accurate determination of the degree of accuracy will necessitate field check. A simple correlation matrix of the lab measurements to the field check may prove helpful in expressing remote sensing applicability especially in working with such finite objects. Smaller scales will be utilized for general location, coastal orientation, and overall symmetry (beach closure) about the cusp field. Any measure proving inherently too difficult from remotely sensed imagery will have to be made in the field.

A variety of multi-variate statistical techniques may be implemented to find the correlation between the above parameters. This will occur for the values in one field, for the values between fields and perhaps, through trend surface analysis and/or time series analysis, the correlation of form and process on a seasonal basis may result. Working within a geomorphological framework, it is imperative to analyze the findings with the expectation that one must relate the results back to some reliable theory. By such means, an attempt to separate the controlling factors from the irrelevant and to establish a distinct set of variable interrelationships inherent to cusp formation will be made.

4.2.3.3 Anticipated Results

The implications of the research just described are many. Principally, the applicability of remote sensing to coastal geomorphic research is of importance, but it is the relevancy of locating and studying small isolated features not depicted on topographic maps that may establish the value of remote sensing. Secondly, by analyzing cusp morphometry and cusp behavior through time intervals, inferences as to cusp origin and destruction may result. Because cusps are erosional in nature, and do disrupt normal beach appearance and profile, the more that is understood about cusp-related features and the crucial variables controlling their being, the better will be the changes of preserving valuable beach property. This is of particular importance at such a beach as Newpoet and no doubt will pertain to coastal areas in general.

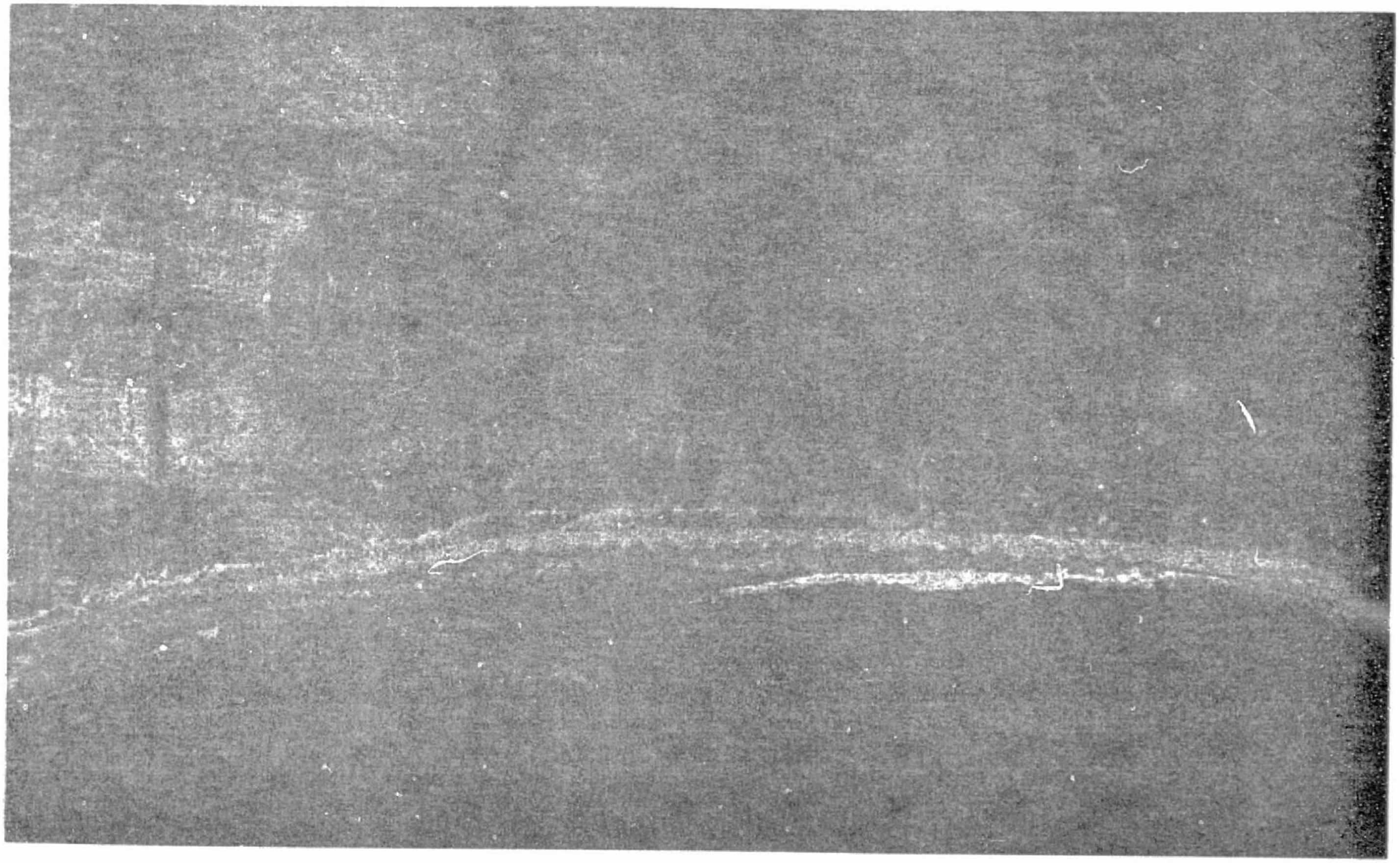
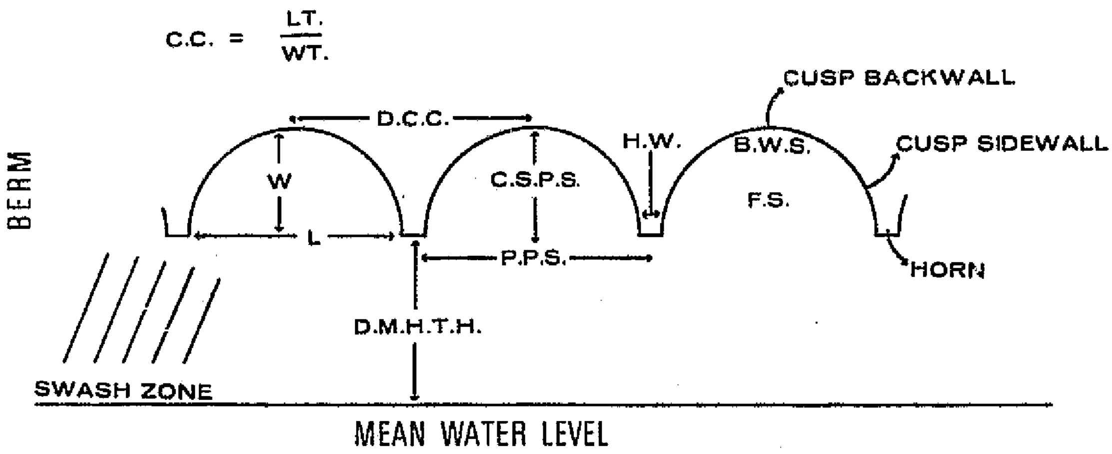
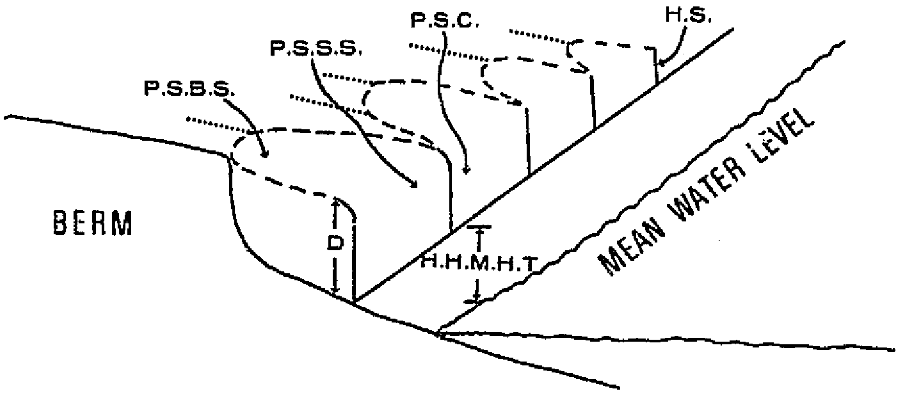


Figure 4.8. Black and White photo of original CIR Image of the southern California coast line south of Newport Beach, California and north of Laguna Beach showing the extreme cusping of the beach sands. (NASA-Ames U-2 photo August 14, 1975. Nominal photo scale 1:7,860 from original scale of 1:32,500)





Geometry

L= length

D= depth

W= width

s.w.s.= side wall slope

b.w.s.= back wall slope

f.s.= floor slope

c.c.= cusp closure

v.= volume

h.w.= horn width

h.s.= horn slope

d.c.c.= distance from cusp centers

Particle Distribution

p.s.b.s.- mean particle size backslope
p.s.s.s.= " " " sideslope
p.s.c.= " " " center
c.s.p.s.= " " " cro s-section
p.p.s.= " " " plan

Wave Relationships

d.m.h.t.h.= distance from mean high tide to horn
h.h.m.h.t.= horn height above mean high tide

w.h.= wave height

w.p.= wave period
w.a.a.= wave approach angle
c.l.o.= coast line orientation

Table IV

4.3 FUTURE STUDIES

The Riverside Campus Group plans to bring to a conclusion the current studies of water demand of the Santa Ana River Basin in the coming year and to increase research in three areas: 1) the application of LANDSAT data to water demand, 2) the application of remote sensing in the redesign of population versus water demand relationships, and 3) the conduct of further studies of the coastal environment.

4.3.1 Water Demand Studies

Having completed the detailed (second level of classification) identification of land use as the primary driver in the water demand model for the Upper Santa Ana River Drainage Basin we have now questioned the Department of Water Resources (DWR) on the necessity for such fine detail. The DWR has indicated that perhaps their water demand forecasts could be predicted from knowing only three first level classifications of land use (i.e. those applied to urban lands, irrigated lands, and irrigatable lands, respectively). However, this theory needs to be researched and tested. The significance of such a reduced level of classification is that it can probably be obtained from satellite (LANDSAT) imagery. In addition, the use of the three-part classification creates another investigative problem with urban lands, because the DWR is switching over to determining urban water demands by means of per capita water consumption. The population data, however, are not furnished as frequently as desired, nor in the same sub-units as have been established by the DWR. A new requirement now exists to determine the ability of remote sensing to provide inter-census data and to provide information as to the areal distribution of the census data. Therefore, two specific studies concerned with water demand have evolved.

4.3.1.1 Application of LANDSAT data to water demand

Utilizing the detailed land use data derived from high altitude aircraft imagery, we will compare the ability of LANDSAT to provide urban and irrigated land use defined to 4 hectare (10 acre) parcel size utilizing a map scale of 1:62,500 as the base map. A comparison with water demand data, will be made in order to establish the difference in the cost-benefit of the two systems.

<u>It is proposed that the Riverside campus study the use of remote sensing in the correlation and reparceling of census and inter-census data to a variety of user defined planning units.</u>

4.3.2 Studies of the Coastal Environment Using Remote Sensing

In our first six months of investigation of the southern California coastal area to determine areas where remote sensing research can be of aid to public agencies in solving environmental problems, we find two categories of problems. The first category deals with problems created by human interaction (i.e. land use allocations, traffic distributions, etc.). The second category deals with the physical change resulting from human activity interferring with the processes of nature. We propose our research for next year in the coastal environment continue in these two categories as follows:

4.3.2.1 Assistance to Public Agencies in Land Use & Transportation Planning

As indicated in the preceding reports we have found several government agencies at various overlapping levels obtaining data sampled at time intervals of up to ten years. Remote sensing has been used sparingly by each of the agencies who cooperate in sharing their data. The Southern California Association of Governments (SCAG) has been instrumental in coordinating the interaction between agencies in various land use and transportation planning problems. SCAG transportation planning officials are interested in having research conducted to show which of the various categories of planning data can be obtained to a common time base at the best cost-benefit ratio.

It is proposed that the Riverside Campus Group investigate the suitability of remotely sensed imagery to aid in the development of a coastal zone activity change simulation model. The purpose of the model would be twofold. First, by selection of appropriate data retrievable from the imagery, a parameterized coastal interaction zone could be developed. It is proposed that this model include (but not necessarily be restricted to) land use aspects of: housing patterns, commercial and industrial groupings, transportation and recreation.

Second, from land use data, analysis of subsequent imagery, and other data sources, proposed activity changes (e.g. specific land use, transportation corridors, recreational facilities) can be analyzed to project possible impact within the established coastal interaction zone.

4.3.2.2 Studies of the Changes in the Natural Coastal Environment

For many years the natural environment of the southern California coastline has been altered as a result of human attempts to protect living areas. Much of the activity has been in relation to upstream flood control. Some activity has been to conserve the diminished supply of beach sands. Until recently, however, little concern was given to preserving the ecology of areas such as lagoons and marshes. Data are needed on the current status of the coastal environment, before planners can make efforts to preserve the diminishing coastal resources. Remote sensing can provide a cost effective means of obtaining these data as well as an ability to determine the dynamic changes caused by seasonal variations.

It is proposed that the Riverside Campus group conduct remote sensing investigations of the southern California coastal environment to determine the current status and to analyze the effects of change on the natural environment in order to aid public agencies in developing methods of protecting and/or preserving the remaining natural resources. Examples of specific studies are outlined below:

4.3.2.2.1 Coastal Lagoon and Marsh Study

The Ria coast of southern California from Newport to San Diego, is marked not by uplifted beach terraces, not by sharply-incised valleys which have been filled with sediment as a consequence of the Holocene

(post-glacial) eustatic rise in sea level. Where these rivers meet the ocean, the cliffed shoreline opens into a broad flat, usually fronted by a sandy beach with a lagoon behind it. Varying rates of discharge from the streams cause some of the beaches to be breached, others to fully impound the stream's flow.

These marsh-lagoon areas, highly active biological environments, are seriously affected by coastal land use. Sedimentation, pollution, and beach erosion can be stimulated by changes in neighboring land use, and these processes can be permanently changed by direct development, such as dredging, filling, channeling and other "reclamation" activities.

Structural features of coastal marshes and lagoons are clearly visible on CIR imagery even at typical U-2 scales. Remote sensing of these areas will make possible an inventory of this valuable tideland environment, and evaluation of the present level of disruption due to man's activities. Higher resolution imagery (i.e. image scales between 1:10,00 and 1:30,000) should be investigated for properties of vegetation distinction as well as for providing a basis for more detailed geomorphic analysis. A high level of information extraction might also be possible using photo-enhancement techniques such as density-slicing or custom-tailored filter packs.

4.3.2.2.2 The Surf-Zone: Beach Sand Movement and Changing Beach Morphology

Intensive development of the southern California coastline has had a profound effect on the "sediment budgets" of the beaches. Groins, jetties, seawalls, marinas, harbors, and flood control projects all influence local beach morphology and the movement of beach sand.

Many beach forms, especially rhythmic features such as cusps, are clearly visible in remotely sensed images. These forms, especially when viewed with moderate water penetration to show sub-surface turbidity, can tell much about near-shore coastal currents and allow the interpreter to map sediment movement along natural coastlines and around man-made barriers.

Knowledge of sediment movement is valuable for the planning and management of safe marinas and harbors, as well as being useful for planning of recreational beach uses. In addition, remote sensing offers the most practical way to monitor seasonal changes in the beach sediment system, and to identify areas that are exceptionally vulnerable to storm-wave erosion, a major cause of damage to beach front property.

4.3.2.2.3 Environmental Studies Utilizing Thermal Infrared Imagery

The acquisition of a thermal infrared scanner has added a new dimension in sensors available on a continuing basis to environmental studies in California. The power plant operation problems, the refinery problems and the automobile freeway problems (all of which constitute environmental pollution concerns) are responsive in a very different way, when imaged by a thermal scanner. The thermal effects of these hear emitters may lead to a better understanding of their effects on the environment.

Chapter 5

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CHAPTER 5

SOCIO-ECONOMIC ISSUES IN WATER RESOURCE MANAGEMENT

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5.0 INTRODUCTION

The present philosophy of openness in the administration in Sacramento is reflected in the management of California's water resources. It is in this climate of candor that controversial decisions in their many dimensions are subjected to scrutiny. Matters heretofore skirted as being too sensitive politically for discussion and, therefore, shelved for strategic reasons are now receiving attention. Public participation is no longer a pro forma exercise; it is actively solicited. Governor Edmund G. Brown, Jr., Claire T. Dedrick, the Secretary for Resources, and Ronald B. Robie, Director of Water Resources, as well as their associates, practice a type of management style that challenges old assumptions, critically examines facts and figures long regarded as sancrosanct, and earnestly seeks to expose alternative decision paths with a realistic awareness that they are actually complicating the decision-making process.

Not unexpectedly, the socio-economic aspects of water management are coming to the fore and are much more clearly visible than previously. Some of this emphasis can be attributed to recent federal legislation requiring environmental impact assessment, broadly conceived to encompass the social environment. This emphasis may in turn be a reflection of a general state of awareness on the part of the public. Nonetheless, however derived, California's explicit concern that due consideration be accorded all pertinent factors in water decisions is clearly discernible and intrinsic to official policy, as reflected in a statement, drawn from a recent report, that acknowledges that many of the decisions soon to be made "could affect the future lifestyles and well-being of our citizens."[1]

Thanks to excellent working relations with the California Department of Water Resources and the State Water Resources Control Board, as well as with some of the federal agencies involved in California water management,

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[1] California Department of Water Resources, Water Action Plan, A Program for Revision of the Water Management Element of the California Water Plan, September, 1975, p. 7.

members of the Social Sciences Group have been permitted to sit in on key meetings so as to observe at first hand how issues are addressed and plans assessed. Officials of the various agencies, departments, and divisions have given generously of their time for personal interviews and have supplied us with data, records, and other valuable source material.

This high level of cooperation comes about because of the express interest on the part of the State in helping us gain a broader and deeper comprehension of their concerns so that ultimately our research effort will be available and useful to them. This mutually supportive relationship is consistent with NASA's public service orientation, especially its specific mission relating to facilitating decision-making processes through utilization of advanced techniques for the acquisition of information. It is also consonant with the way in which the University of California construes its service obligation as research arm of the State.

The first section of this report will review the Department of Water Resources' new water action plan. The second section of the report will consider the functional relationships between water and other basic resources--land, energy, and the like. Here, the total socio-economic force field is involved, and in a time frame that embraces present and future. The state of the economy and the economy of the state are germane in this connection, since growth policies, land utilization, energy sources, and quality of life desiderata are all inextricably interwoven in the complex and paradoxical pattern of being both cause and consequence of water decisions. A related part of this section will deal with the jurisdictional relationships among the various agencies responsible for resource management at the state level and those existing between State and Federal levels. It is at this point that there occur some of the most difficult and perplexing problems besetting the management of water. The next section will be devoted to the ways in which environmental impact is assessed. Along with a report on techniques currently used, there will be a detailed review of a number of instances of citizen participation, which is now a mandatory element of the assessment process. The final section of the report will present the forward look--our plans and prospects for the coming year.

5.1 THE NEW WATER ACTION PLAN

It may be noted at the outset that the prevailing philosophy of openness, in legitimating acknowledgement of controversy, has not contributed to facile solutions. Quite the contrary. Reality is not simple, and the expediency that has dictated strategic avoidance of politically sensitive issues has, in the past, encouraged a proliferation of sterile, plastic-bound studies that failed to embrace the often baffling socio-economic implications of water policy. Anticipating publication in the summer of 1977 of the bulletin, "The Water Management Element of the California Water Plan," the DWR is in the process of pondering various water management actions and in so doing appears to be shifting emphasis from its role as developer to that of manager. The new plan, as set forth in

September 1975,[2] stresses the flexibility called for by changing social and environmental goals, conservation, and better utilization of existing supplies. The features to be included in the two-year plan are intended to accomplish the following[3] .

(1) Provide the basis for administration policy concerning allocations of water supplies and priorities for expenditure of funds by federal, state, and local governments for water utilization, conservation, and development.

(2) Identify and evaluate problems of water supply, demand, and quality and those flood damage problems which can be corrected as part of water supply solutions.

(3) Provide for greater consideration of fish, wildlife, recreation, and related instream water needs, including preservation of riparian habitats.

(4) Identify and evaluate alternative solutions to specific problems.

(5) Provide a basis for the fully coordinated operation of the Central Valley Project and the State Water Project.

(6) Develop bases for assigning responsibility for maintenance of Delta water quality requirements.

(7) Recommend courses of action with regard to individual issues and problems.

Intrinsic in the program outlined above are four basic study elements: (1) Water conservation; (2) Areal studies; (3) Water Project operation studies; (4) the State Water Project. Under (1) conservation methods, practices, and devices will be investigated, with a myriad of possible measures evaluated. Suggested are improved agricultural practices, modernization of water distribution systems, revision of building codes, analyses of industrial and agricultural water uses, and effects of pricing on water use. Ultimately, there will emerge from this effort identification of possible methods of water conservation, with an assessment of the pro's and con's of each, specification of locations, typical and general, of potential applications, calculations of possible savings in water, and estimation of likely means, costs, and impacts of implementation. Included

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[2] California Department of Water Resources, "Water Action Plan, A Program for the Revision of the Water Management Element of the California Water Plan," September, 1975.

[3] Ibid, pp. 7-8.

in the latter category are effects on local water demand and supply, water quality, waste disposal, the environment, and the economy.

The main emphasis during the ongoing two-year period is on the areal studies, for here the task is to reappraise water demand and supply estimates, consonant with projected population levels, municipal and agricultural needs, water quality and environmental exigencies, updated water-pricing policies, and improved irrigation methods and conservation practices.

Interesting to note, a base element for each of the areal studies will be the population, land use, and water demand projections presented in the DWR's Bulletin No. 160-74, "The California Water Plan--Outlook in 1974", and discussed in our Semi-Annual Progress Report of 31 December 1974. Modifications are anticipated to include an array of inputs of both socio-economic and technological significance. As examples of the typically socio-economic, we find reference to land-use planning, water pricing practices, social impacts of water and energy conservation measures, and the possible reduction in water demand brought about through change in crop patterns. Consistent with its goal of achieving a unified plan -- one that embraces the management and the quality elements -- the DWR coordinates its activities with the State Water Resources Control Board and its 9 regions, which, under the Porter-Cologne Act of 1969, has just completed water quality control plans for California's 16 major hydrologic basins. Their recommendations regarding environmental protection, fish and wildlife preservation, recreation requirements, and water quality standards are to be incorporated into the revisions of water allocations. Reflecting again the intent of the administration to keep the public informed of crucial decisions, the new calculations regarding water allocations will be discussed with affected local interests and the Advisory Panel[4], with modification made where necessary. Especially important from the hydrological point of view are the results of reevaluating risks of dry-year recurrence and the varying water deficiency criteria.

In each area study, issues specific to the region will be given particular attention by the district offices. For the Trinity River area, for example, instream and transbasin diversion requirements of that division of the Central Valley Project will be reassessed. The ravages of timber harvesting malpractices in the Upper Trinity River watershed, and the consequent sedimentation problems, will be appraised and restoration procedures instituted. The Central District presents unique characteristics. Water service areas within the Russian River Basin derive their supplies from ground water, from local surface water developments such as the Lake Mendocino Project (U.S. Army Corps of Engineers), and from the Upper Eel River Basin by way of Pacific Gas and Electric Company's power diversions. With PG & E's license for this project up for renewal by the

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[4] The eight-member California Water Advisory Panel is also referred to later. See footnote 25.

Federal Power Commission, under scrutiny is the appropriate level of diversions to the Russian River when instream requirements of the Upper Eel River are under consideration. Management of the Russian River area is further complicated by vulnerability to floods, especially in the vicinity of Guerneville.

As to the Southwestern Sacramento Valley (the Central and Northern Districts), there seems to be a need for updating of essential data having to do with land use, cropping patterns, unit water use, and economic development criteria, since indications are that the federal water pricing policies and payment capacity estimates of ten years ago are no longer pertinent. The Southeastern Sacramento Valley, due to be served by the Folsom-South unit of the Central Valley Project, faces continued fall of water tables because of the pumping of ground water for industrial, municipal, and agricultural uses. It is in this latter category that requirements are slated for reappraisal, attention to be directed to projections of demand buildup, especially in view of likely rises in the price of federal reclamation water.

In the East Side San Joaquin Valley, the mining of ground water, with the consequent lowering of water tables and, at the same time, rising pumping costs and energy consumption, is a major concern. Because of consolidation of aquifers and increased concentration of salts in lower water volumes, land subsidence is a severe threat. In view of the current and increasing overdrafting of ground water supplies, various alternative plans will be considered. Importation of water via canals and more stringent conservation efforts are among them and will be appraised, there having been taken into account a revised scenario for water requirements as limited supplies and environmental, social, and economic desiderata are realistically taken into account. It is in this San Joaquin District that issues related to the New Melones project must be resolved. Under California Water Rights Decision 1422, stored water in the New Melones Reservoir may be used for Stanislaus River instream purposes, such as fisheries, wildlife, recreation, and maintenance of water quality. Decision 1422 restricts utilization of storage to that water necessary for temporary flood flow retention use and, for similar purposes, to augment river flows. This restriction was designed to protect upstream river values and was to remain in effect until such time as a need for agricultural or municipal water supplies in an associated area will have been firmly established.

In October, 1975, in a case titled United States v. California, United States District Court Judge Thomas MacBride handed down a decision that virtually undermines Decision 1422 and, moreover, is likely to have profound effect on the entire spectrum of water resources management in California. The litigation devolved on the question of whether the U.S. Bureau of Reclamation, in operating its projects, is required to meet the same standards and rules applicable to the DWR and to private individuals. Judge MacBride ruled that the federal agencies are not required to comply with the conditions in State Water Resources Control Board Water Rights Decision No. 1422. Although the lawsuit was over the New Melones, the

decision is likely to affect matters related to the Delta as well as to all U.S. Bureau of Reclamation rights permits and licenses. If the decision were, as it might, to place on the State Water Project the full responsibility of meeting water quality criteria in the Delta, the ability of the Project to meet its full contractual commitments would be jeopardized. In other of the areas mentioned as under study, i.e., those which have relationship to Bureau of Reclamation projects, similar problems might be created. There is a range of issues intrinsic to the management of California's water resources that may be seriously affected if Judge MacBride's ruling is upheld. The implications are far-reaching.

Drainage problems are especially prevalent in the studies in the West Side San Joaquin Valley, where disposal of agricultural waste waters is a central concern. Due to soil conditions, saline return flows are trapped near the ground surface and ultimately could so reduce potential for healthy agricultural crops that this area of fertile farmland could be ruined. The South Bay-Central Coast Area faces realistic reassessment of its supply and demand situation. At present relying on ground water with some importation, the region may need to re-examine earlier projections as to population growth and agricultural expansion. Here, as in other districts, quantities and timing of need for water deliveries might be found to be sensitive and responsive to revised water pricing policies and more determined conservation and reuse measures.

Maldistribution, poor quality of local surface water, and deterioration of ground water quality are items high on the agenda of the Southern District (San Luis Obispo and Santa Barbara Counties). One of the basic questions raised in this as in the other areas has to do with the economic, social, and environmental implications of not meeting water demands as projected earlier. The South Coastal Area is probably supplied with sufficient water until the year 2000, but if recent population and industrial development forecasts are reliable, it could benefit from better water management practices, e.g., greater utilization of reclaimed water, more effective use of ground water, water exchanges, and reduction in demand through conservation. For the Owens-Mono District attention will be given to the economic and environmental aspects of water exportation.

In addition to the individual section studies, the DWR is inquiring into policies and operational theory underlying the State's major water systems, viz., the State Water Project and the Central Valley Project. In coordination with studies being conducted by the Bureau of Reclamation, the DWR plans (a) to develop estimates of water yield; (b) to locate additional water exchange possibilities between project systems; (c) to devise methods for more utilization of ground water when surface water supplies are deficient; (d) to run various sensitivity analyses to ascertain physical opportunities and socio-economic and environmental effects of changing project operational criteria with different balances among project purposes, the objective being an enhancement of instream water values; and (e) to calculate the degree of risk associated with modifying traditional deficiency norms for project operation during critical dry periods.

The hydrologic evaluations thus accomplished are seen as an essential input for several of the State's most pressing water management problems: (1) the Peripheral Canal and other ways of meeting the Delta's and export requirements and (2) definition of the need for, and timing of, supplemental yield facilities for the State Water Project.

In brief review of all the areal studies, some of which are already under way and in various stages of completion, and of the overall operational and policy review, it may be observed that there is considerable emphasis on current, valid, up-to-date information. Also noteworthy throughout are examples of the very aspects of water management that have continued to be the focus of research by the Social Sciences Group since the inception of the University of California Remote Sensing Project. Outstanding among these are the functional relationships between water and other resources; water as a factor in and as affected by growth and development in the society; jurisdictional and bureaucratic relationships and the way in which they impinge on water management; water in its relationship to the total environment and as assessed through environmental impact studies; decisions regarding water and the processes by which public participation is invoked. In virtually all of these aspects, the potential for effectively employing remote sensing is tremendous.

5.2 WATER MANAGEMENT INTERRELATIONSHIPS

A review of current issues within California's primary water management agency is incomplete without describing how DWR concerns relate to those of other resource management agencies. Water policy decisions, as emphasized in our May 1975 progress report, are not simply the fruit of some well-pruned "decision tree". Instead, the water policy decision environment more closely resembles an unruly "bramble patch", thoroughly intertwined with networks of overlapping jurisdictions. Untangling and separating the various influences on water management decisions into meaningful categories is a thorny problem at best. Nevertheless, in this section we attempt to delineate some of the main functional and jurisdictional areas that affect water management decision-making in California.

As already mentioned, the DWR appears to be shifting emphasis from a posture of <u>resource developer</u> to that of <u>resource manager</u>. This metamorphosis has significant implications for an information-rich technology like remote sensing. Although both development and management functions require information regarding costs, environmental impacts, and so forth, the management function, in particular, requires information of a continuous and periodic nature for <u>monitoring</u> the performance of a resource management system. Accurate and timely monitoring becomes all the more important when one is trying to stretch a given resource over more users (<u>e.g</u>. water conservation), or to measure negative side effects of stretching that resource too far (<u>e.g.</u>, pollution, salt water intrusion, subsidence). Satellite remote sensing technology, in combination with airborne and ground-based sensors, is already capable of augmenting substantially the repetitive information needed to monitor and manage many aspects of California's water and water-related resources.

Realization of specific remote sensing applications, as reiterated in numerous conferences, symposia, and special reports, is complicated by the diffuse nature of the "user community". Unlike a technological development that serves a well-defined group of users (e.g., the jet engine), remote sensing satellites are characterized by an extreme diversity of applications and potential users. The applications, moreover, often require that remote sensing information be used in conjunction with other information sources, such as ground-based sensors. Economists sometimes refer to such multiple-source arrangements as "joint products"; i.e., product A and product B mutually enhance the utility of the other. Extending this concept one step further, many remote sensing applications might be described as serving "joint consumers", where, for example, remotely-sensed agricultural inventory information might have value for a variety of agency jurisdictions ranging from agricultural land use to water demand forecasting.

New technologies, history teaches us, normally develop from simple to more complex configurations. The development of remote sensing technology is proceeding in this pattern. More and more remote sensing applications are involving multiple users, uses, and sources of data. This makes it especially worthwhile to study the functional and jurisdictional "bramble patch" associated with the community of users in question.

To map thoroughly the bureaucratic undergrowth surrounding California's water management community is a virtually impossible task. For one reason, the water management environment is too extensive: boundaries and generalizations must be created to reduce the task to manageable proportions. For another reason, the environment is too dynamic: even if a complete picture could be developed, it would soon be out of date. In the limited scope dictated by this progress report, the best we can hope to do is roughly to scan this territory while taking note of significant relationships and apparent trends.

Imagine that the length and breadth of our conceptual bramble patch represent water, water-related resources, and their uses. Within the patch's depth are concealed the various layers of public and private organizations that manage or exploit the basic resources. That portion of the patch growing from the water resource stem is particularly gnarled and overgrown. Long tendrils representing the traditional "economic" water uses (irrigation, industrial and domestic supplies, etc.) intermingle with in-stream and conjunctive uses. Young, rapidly-growing shoots representing water quality and water conservation concerns seem to appear almost everywhere. Water-related resources--energy and land especially--intertwine with the extensive water brambles. Among the inhabitants of this tangle are our familiar water management agencies: the DWR, State Water Resources Control Board, the U.S. Army Corps of Engineers, Bureau of Reclamation, regional and local water agencies, and so forth. Other resource management agencies also live there: the U.S. Environmental Protection Agency, Bureau of Outdoor Recreation, Department of Agriculture, Department of Interior, Energy Research and Development Administration, the State Department of Fish and Game, Department of Food and Agriculture, the new Energy Resources Conservation and Development Commission, and many more.

Obviously, biological analogies have their limits when used to describe socio-economic processes. An important limitation is that of developmental predictability. The life cycles of most common biological networks, including bramble patches, are generally well understood and predictable. This is not so in human society. We have no established methodology for confidently predicting future socio-political climatic conditions, much less how they would affect resource bramble patches and their inhabitants. It is difficult enough to agree on the effects of past social changes or whether there have been any major changes at all! Once again, interpretation difficulties are the result of the enormous extent of social landscape and the huge volume of simultaneous and often conflicting events.

It is nevertheless a worthwhile exercise regularly to monitor the cacophony within resource bramble patches and fluctuations in the surrounding socio-political weather. Every so often, clear signals may emerge from the noise. Water resource management in California, we think most perceptive monitors would agree, is being profoundly influenced by major changes in the larger social environment. The orientation toward growth and expansion of water resource facilities, prevalent in the 1940's and 1950's, appears to be undergoing modification as the result of new perceptions developed in the 1960's and 1970's. We can identify at least three such major changes:

(1) An awareness of new publics

(2) An awareness of negative environmental side effects

(3) An awareness of resource constraints.

The first two of these changes have already generated a mountain of federal and state legislation concerning social justice and environmental protection. As will be seen shortly, the two concerns are officially integrated into environmental impact review processes which require public participation. The third major change is only now beginning to affect resource management organizations, public and private, at local, national, and international levels. The DWR's forthcoming Water Action Plan, described previously, is one example of a public agency's response to a heightened awareness of limited resources.

In the remainder of this section we examine water management interrelationships within three resource areas: water, energy, and land. Recent activities in selected agencies help illustrate how the above-mentioned changes are being translated into policy. In the water area, we discuss an old agency in the process of assuming a new role; in the energy area we describe a new agency attempting to establish itself; and in the land area we discuss a proposed state land-use agency.

The federal role in water resources management has traditionally emphasized the planning and development of those resources. This has created an interesting kind of duality, at least from the point of view of federal

agencies. All water resource developments, whether they are dams or irrigation facilities, are speculative ventures. One can never be positive that the project will work as planned. Also, the projects are usually very costly, much more than most local governmental agencies can afford. Thus, the federal government often becomes the project guarantor because it is able to spread the risk across many projects and areas. The other side of the duality appears at the local level: the true beneficiaries of the project are almost exclusively local in origin. As a result, they usually have difficulty in developing a national consensus for what they wish to do. This "national risk-local beneficiary" duality, according to David J. Allee[5], has had the effect of (1) emphasizing congressional adjudication at the expense of state or federal executive agency involvement, (2) encouraging strong local offices in federal agencies like the Soil Conservation Service and the Corps of Engineers, and (3) insuring an unstable planning process where a national consensus on what ought to be done has to be re-negotiated annually in Washington.

Nationally, the accumulated effects of this local federal agency advocacy and bargaining process have been a growing backlog of authorized but unfunded water resources projects. Secretary of Interior Rogers Morton, in his address before the National Conference on Water, held 22-24 April 1975, described the present backlog of Corps of Engineers and Bureau of Reclamation projects as $20 billion and $7 billion, respectively. This year, annual federal investments in water resources projects are about $6.2 billion, with an emphasis on water quality.

The existence of a large backlog of federally-approved water projects has stimulated efforts to develop a priority system for financing and construction. In 1974 Congress passed the Water Resources Development Act, directing the President to make a study of water resources development principles and standards. The Water Resources Council is also working to develop criteria for more equitable evaluation and selection of projects. At the regional level, the search for more comprehensive criteria and development priorities has stimulated the many water basin planning efforts. California's State Water Resources Control Board completed approval in August of 16 basin plans. The plans are the result of a 3½-year planning effort to designate beneficial uses for California's water resources and to set water quality objectives to protect those waters. It remains to be seen, however, just how much success comprehensive basin planning efforts will have in altering traditional methods of project promotion and development. The national risk-local beneficiary dualism problem is unlikely to disappear even if local sponsors are required to submit projects in correspondence with new regional plans. The Social Sciences Group plans to continue watching with interest basin planning and water resources project implementation efforts in California.

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[5] David J. Allee, "The Changing Role of the Water Resource Planner," in The Grass Roots and Water Resources Management, State of Washington Water Research Center, Washington State University, Report No. 10, 1972. Dr. Allee is professor of Resource Economics, New York State College of Agriculture and Life Sciences.

One apparent result of the federal awakening to the inequities and inefficiencies of earlier water resources planning efforts is a gradual extension of Washington's authority into the local planning affairs and jurisdiction. We have already discussed some of the implications of the October 1975 decision regarding the Bureau of Reclamation's authority over New Melones Reservoir water. The implications stemming from the U.S. Army Corps of Engineers' new regulations in connection with Section 404 of the 1972 Federal Water Pollution Control Amendments may be even more far-reaching.

San Bruno, just south of San Francisco, was one of the four places in the nation where the Corps elected to hold hearings on its Section 404 "Interim Final" Regulations. There, on 12 September 1975, Corps officials held forth for some eight hours explaining the regulations and entertaining testimony from around 50 speakers. The new regulations portend to have a tremendous and far-reaching impact on the management of water resources and, the whole spectrum of related matters, e.g., land use, forestry practices, irrigation, recreation, environmental preservation, etc. It has been interesting to note, at the hearings, the approval of conservationist associations, who look to the Army Corps as protectors of wetlands, the dismay of cattle dealers and forestry industrialists who anticipate more stringent regulations, and outright opposition from some western states, jealous of their rights and resentful of more "federal bureaucratic intervention", their scenario for the future.

Under its original jurisdiction (1899) the Corps confined its permit activities to "navigable waters of the United States". The accepted definition was those waters navigable at present, navigable in the past, and those which could reasonably be developed to become navigable. In April 1974, the Corps published its revised regulations concerning Section 404 of the 1972 FWPCA amendments. The Corps regulations were challenged by environmental groups, notably the National Resource Defense Council, as being too narrow an interpretation of Section 404. In March 1975, a decision by the U.S. District Court of the District of Columbia (NRDC v. Callaway, et al.) greatly expanded the responsibility of the U.S. Army Corps of Engineers to include disposal of dredged and fill material to "the waters of the United States". This more inclusive term, never defined by Congress or the courts, was spelled out by the Environmental Protection Agency in regulations controlling its discharge program under the Federal Act. "Waters of the United States" are now construed as:

(a) all navigable waters of the U.S. and their tributaries;
(b) all interstate waters;
(c) all lakes, rivers, and streams within a state which are used by interstate travelers for recreation and other purposes, those from which fish are taken and sold in interstate commerce, or those which are used by industries engaged in interstate commerce, including agriculture.

The new regulations will expand the Corps' authority over United States water resources both laterally and longitudinally. They are to be implemented gradually in three phases. Phase I, effective 25 July 1975, extended the existing permit procedures applicable to traditional "navigable waters

of the United States" to include contiguous and adjacent wetlands. The Corps considers this primarily a lateral expansion of authority. Phase II, effective 1 July 1976, will add primary tributaries and lakes greater than five acres in area. Phase III begins a year later and extends Corps authority to other "navigable waters" up to the headwaters, where streamflows are five cubic feet per second.

Realizing that administration of these new provisions is liable to prove a difficult and expensive task, the Corps has pledged to give the states as much initiative in the permit approval process as the law permits. Again, it will be most interesting to observe how changes in federal water resources guidelines will affect decisions at state and local levels. The Social Sciences Group intends to watch future events in this area very carefully.

All three of our above-mentioned "major changes" come into play to some degree in the current emphasis on comprehensive basin planning and in the Corps of Engineers' new responsibilities. The third major change--awareness of resource constraints--appears to be making its strongest impact on water management in the area of water-energy relationships. Table 4 in the DWR's Bulletin No. 132-6[6], titled "Annual Project Energy Requirements for Pumping", shows the net energy expected to be required (energy required for pumping minus energy generated at power plants) by the California Aqueduct on periodic bases through the year 2035. Energy generation in the Aqueduct is now roughly 20 percent of the energy required for pumping. This ratio is expected to rise to around 27 percent by 1985. Net energy requirements, now approximately 3.2 billion kilowatt-hours, are expected to rise about 74 percent to 5.5 billion kilowatt-hours in 1985. (Net energy requirements for the whole State Water Project will be about 500 billion kilowatt-hours higher). The great unknown in these projections is the future price at which the DWR will be able to purchase power.

Most power resources to operate the State Water Project are now provided by an energy consortium called the California Suppliers. The group consists of Pacific Gas and Electric Company, Southern California Edison Company, the Los Angeles Department of Water and Power, and San Diego Gas and Electric Company. The DWR completed negotiations on its basic power supply and transmission contracts with the California Suppliers around nine years ago, long before OPEC became a household word with global implications. Energy rates for the State Water Project are due to be renegotiated in 1978 and become effective in 1983.

Fortunately, the DWR has many options to explore before it finds itself overwhelmed by a postponed energy crisis. The developing Water Action Plan will explore possibilities for various pricing policies, water conservation measures, and institutional arrangements, all of which can offer ways of reducing water and energy requirements. Agriculture is one example of an

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6 California Department of Water Resources, Bulletin No. 132-75, The California State Water Project in 1975, June 1975.

area where the DWR might effect significant energy savings. Currently, irrigated agriculture uses about 85 percent of the water delivered by the State. According to figures presented at a recent conference of water and energy[7], it is well within current technological capability to achieve an overall reduction of 10 to 20 percent in the annual energy consumed to generate agricultural water supplies. Potential reductions are much greater, around 50 percent for certain crops. Barriers to achieving this savings potential are mainly sociopolitical and not technological. Among the means for reducing energy requirements for irrigation are (1) reducing water application, (2) increasing pumping efficiencies, (3) reusing irrigation runoff, (4) reducing peak water demands, and (5) improving irrigation system design. Similar improvements, well within current technical capabilities, are possible for also reducing energy consumption in municipal and industrial water uses. Remote sensing is proving its worth with respect to these various means as detailed elsewhere in this report.

Perhaps one encouraging aspect about the new awareness of resource scarcity is that it reveals with unusual clarity some fundamental relationships between the supply of basic resources and the environment. Energy, for example, is derived from two principal sources: either the stock of hydrocarbon and uranium deposits embedded in the earth, or the flow of solar energy intercepted by the earth. Several other sources of energy exist (e.g., hydroelectric and geothermal power) but they are relatively minor items in the global energy budget. Environmental stresses can be reduced by shifting from energy stocks to energy flows, or by living off "energy income" rather than the global capital endowment. Economist Nicholas Georgescu-Roegen emphasizes that environmental degradation must be measured not only in terms of pollution but in terms of depletion of stock resources as well.[8] Water, an essential element of all biological and most economic processes, is an especially significant and vulnerable part of the environment. The efficiency and care with which water and related resources are used can profoundly affect environmental quality. Mechanized agriculture, with its heavy pesticide, fertilizer, and water requirements, epitomizes an economic activity with a high environmental price both in terms of pollution and nonrenewable resource depletion.

Formal acknowledgement of water-energy interrelationships within California government took place in the 7 November 1975 regular meeting of the California Water Commission. There, Dr. Richard L. Maullin, Chairman of the newly-created Energy Resource Conservation and Development Commission briefed the water commissioners on the ERCDC's responsibilities and plans

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[7]Darrell G. Watts, "Agricultural Water Supply", in Nebraska Water Resources Research Institute, The Role of Water in the Energy Crisis, Proceedings of a Conference, 23-24 October 1973, Linclon, Nebraska, pp. 114-127.

[8]Nicholas Georgescu-Roegen, "Energy and Economic Myths", Southern Economic Journal, 41, January 1975.

for the future. Maullin described DWR and ERCDC mutual interests in the following areas:

(1) forecasting energy requirements for irrigation

(2) determining the amount of water needed for power plant cooling

(3) forecasting the energy produced from hydroelectric power

(4) cooperating in a planning role to help determine how best to use and conserve water and power supplies.

ERCDC began operations on 17 March 1975, following the Governor's appointment of five full-time energy commissioners. The commission's responsibilities are spelled out in AB 1575, authored by Assemblyman Charles Warren in 1974. Major areas of jurisdiction include power plant facilities siting, forecasts and assessments of energy needs, energy conservation, environmental and social impacts of utility operations, and energy research and development. The commission has already acquired about 40 percent of its staff, expected to be about 270 next year. The commission's funding is provided by a surcharge levied on the retail sale of electricity

Although the energy commission is still in its formative stages, it possesses sufficient powers eventually to have a major impact on the water-energy and land-use environment of California. One impetus behind the commission's creation was the concern of the AB 1575 supporters that the existing Public Utilities Commission had become overly sympathetic to the desires of utility companies. Thus, ERCDC will gradually relieve the PUC of its power-plant siting responsibilities. The energy commission has also made inroads into PUC authority in the area of electrical pricing authority. By June 1976, ERCDC will have established for PUC review new policies covering rate restructuring, peak-load pricing, and curtailment of certain electrical uses. The energy commission's potential to affect land uses stems from its powers to establish construction standards and to freeze development in certain areas. Whether a special purpose agency like ERCDC could or should become a de facto statewide land-use planning agency are questions for serious consideration. In any case, the Social Sciences Group anticipates that this new agency will be playing a much greater role in many aspects of problems regarding California's resources.

It should come as no surprise that linkages between energy and land resources also imply land and water linkages.

> One of the basic truisms in resource management is that whatever you do to land influences water and, at the same time, whatever you do to water influences land use.[9]

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[9] William R. Walker (Director, Virginia Water Resources Research Center, Blacksburg, Va.), "Integrated State Land and Water Policy: Complements and Conflicts", in Virginia Polytechnic Institute and State University and Virginia Water Resources Research Center, Land-Use Issues, Proceedings of a Conference, Publication 629, November 1974.

This observation is especially appropriate to California Water management right now. As can be seen from the foregoing sketches of geographic, operational, and policy areas of concern, the emphasis is on water in the present and future framework of its functional relationships. Perhaps nowhere is the web more tangled and complicated than in that part of it which ties water to land-use planning.

What are the major problems and issues to which State land use, resources management, and environmental quality legislation should be addressed? Studies by a California land task force[10] included the following:

1. Coordinating State level planning which affects land use and environmental quality, e.g., the California Transportation Plan, the coastal plan, the Tahoe plan, the water plan, planning for energy, air and water quality, resources conservation and recovery.

2. The conflicts between growth, resource preservation and conservation, and quality of life, conflicts which are so evident in our urban fringe areas; specifically:

   a. Air pollution continues to cause severe damage to humans and crops.
   b. Our store of natural resources dwindles rapidly, unable to keep up with ever growing demands.
   c. Farmland continues to be converted to urban uses, seemingly without thought for the future needs of the State.

3. The need to maintain a healthy economy, provide necessary housing, and assure liveable and viable urban areas while conserving resources and protecting the environment.

   Suburbs expand across vacant lands, older downtown areas are rapidly declining while at the same time, the housing shortage--especially for people of low and moderate income--increases.

4. The ever-increasing costs of the systems which serve our needs--energy, water, waste, transportation, public services.

5. The multiplicity of special and general purpose governments in the state, particularly in the major urban areas, resulting in not only problems of coordinative planning and the provisions of services, but also in a complex and unworkable system of conflicting controls, standards, regulations, procedures, and permits.

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[10] The Land Use Legislation Task Force was formed following a land-use conference in February 1975 and consists of a diverse group of administrators, environmentalists, and planners. The group helped in the drafting of Z'berg's AB 2422, the six major objectives of which are described on the next page.

6. The special cooperative planning attention, management and protection necessary for unique, fragile, and critical environmental areas of the State.

Along with New York State, in its establishment of a special agency to protect the Adirondacks, California leads the nation in implementing measures designed to protect the environment. Assembly Bill No. 2422, introduced in the California Legislature on June 25, 1975 by the late Assemblyman Edwin L. Z'berg, is now referred to as the State Land Use and Resources Management Planning Act of 1976. Its major objectives, as set forth by the Assembly Committee on Resources, Land Use, and Energy, under its Chairman, Charles Warren, are as follows.[11]

(a) to develop and establish coordinated and comprehensive State land use, resources management, and environmental quality goals, objectives, and policies to guide planning and programs of all levels of government;
(b) to develop a comprehensive State land use and resources management plan, and regional plans for major metropolitan and special areas.
(c) to coordinate the planning of State agencies to assure consistency with the State plan; resolve conflicts between the State plan and plans and programs at all levels of government;
(d) to interrelate environmental and energy standards with land use and resources management plans;
(e) to assure coordination and consistency between plans and programs of all levels of government to achieve optimum levels of environmental quality considering economic, social, and energy needs and impacts;
(f) to assure adequate protection and management of critical resources and areas.

As with the recent establishment of the California citizens' coastal commission, Governor Brown has indicated deep concern with the rightful responsibility of local government in land-use planning. A statement about his position on that occasion applies equally well here: "He clearly recognizes the complexity of the problems and passions created by any effort to balance private equity and the health of the local economy with the public's right to a wise over-all use of the land."[12] Reference to the accompanying organization charts indicates the many linkages, explicit and implicit, between water and land use and environment. Only time and experience will tell whether and the extent to which this commendable effort will overcome the inherent difficulties in land-use planning. Comprehensive plans are usually too broad and vague to serve as working guidelines; local plans

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[11] Committee statement accompanying notice of hearings, September 26, 1975.

[12] Editorial, "Gains for Land Use," The New York Times, November 21, 1975.

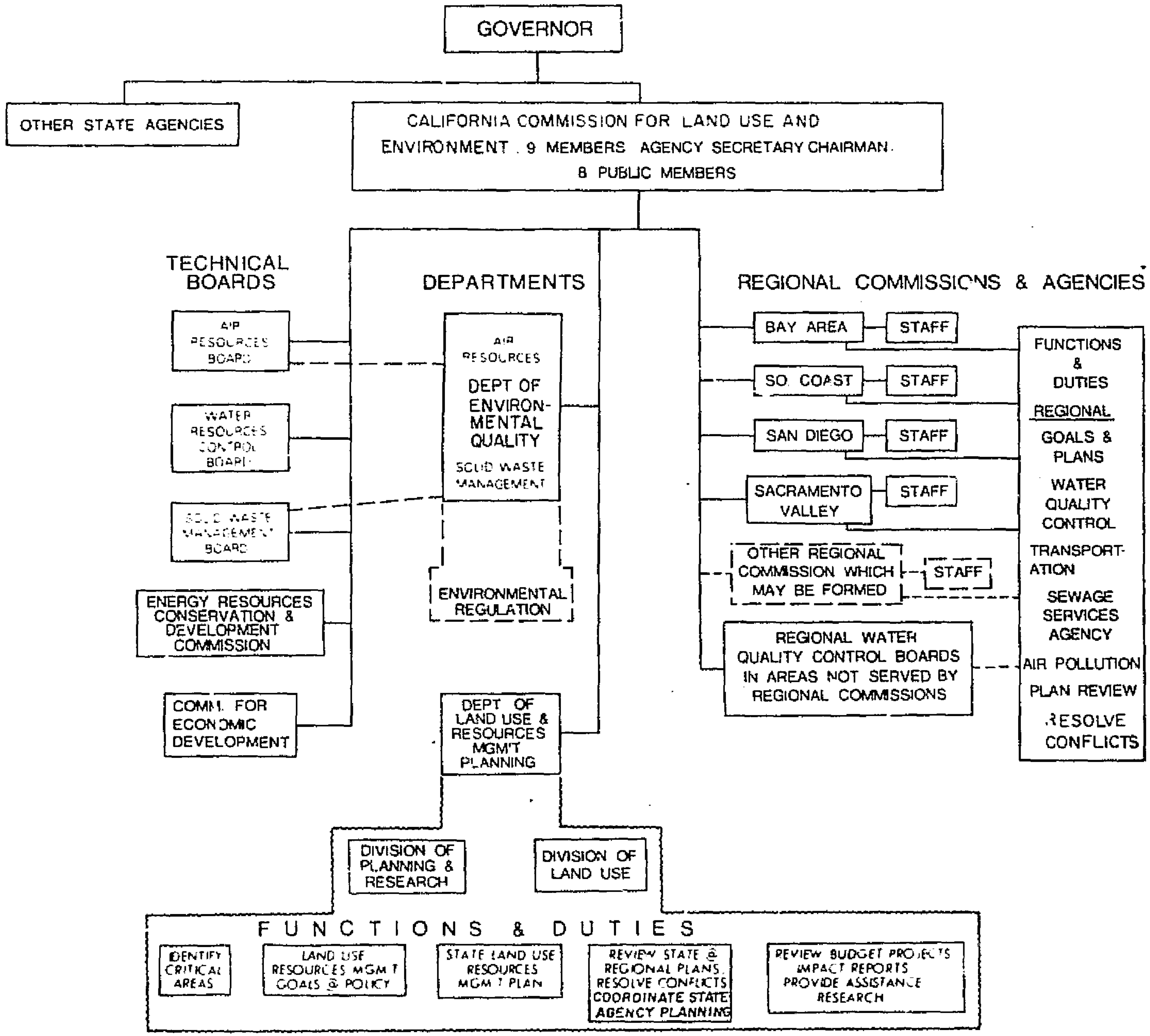

Figure 5.1 Diagram depicting the organizational structure which governs the multifaceted operations of the California Commission for Land Use and Environment.

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EXISTING STATE ENVIRONMENTAL ORGANIZATION

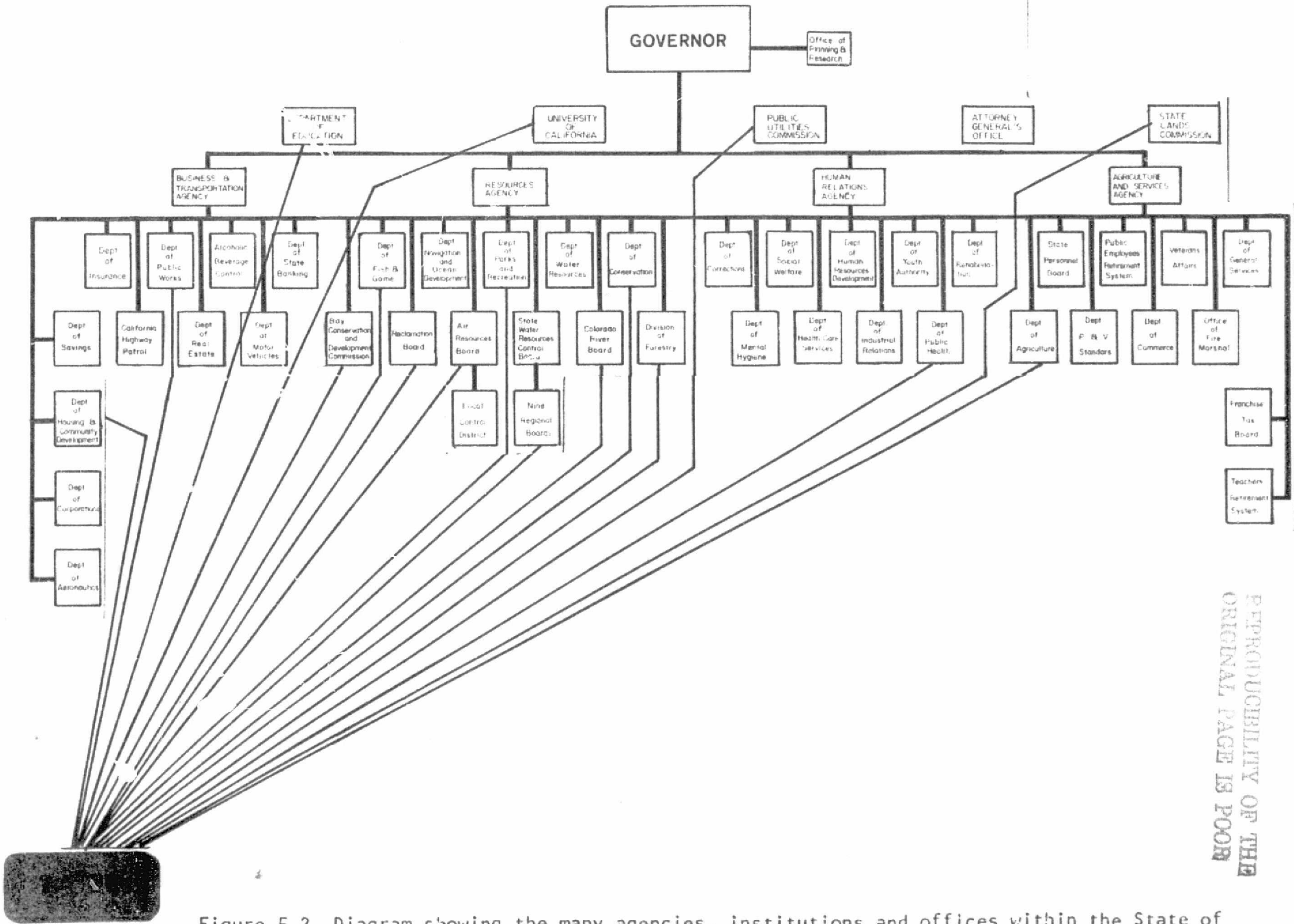

Figure 5.2 Diagram showing the many agencies, institutions and offices within the State of California that have interests in water and land use, particularly from the environmental standpoint.

are generally likely to reflect the shortrange, immediate, and often "isolationist" interests of a community. Thus, the current state of the economy in some places or alarm over excessive immigration in others have been seen to influence land-use decisions. Public participation is sought, but people tend to polarize around certain controversial issues and the same old power struggle prevails. Despite its theoretical appeal, "the public interest" is far from a homogeneous, unanimous expression; there are many publics. Their interests diverge, but they often coalesce in unlikely ways, depending on the particular matter under consideration. The numerous instances where environmental impact assessments are being challenged as selective, biased, inadequate, and so on attest to the fact that in such complex matters as these, there is no one indisputable and immutably right position.

When one considers the elements of a truly thoroughgoing and comprehensive land-use plan, one can understand both the difficulty of capturing adequately all the necessary inputs and the multiplicity of occasions for legitimate dispute. Some of the following have been suggested: existing land uses; growth trends; natural site characteristics; population densities and movement; economic factors; labor market situation; flood control measures; transportation facilities and modes; land area and types required for agriculture, forestry, industry, and transportation; quantity, quality, and price of water and energy. Comprehensive decision-making in the land-use area thus resembles, and indeed often includes, decisions regarding water resources. In both instances, decision-makers must be prepared to tread their way through a veritable wilderness of intertwined functional and jurisdictional brambles.

5.3 ENVIRONMENTAL ASSESSMENT AND PUBLIC PARTICIPATION

Planning processes traditionally have been concerned with the consequences of alternative decisions. Only recently, however, has preoccupation with environmental impacts become an integral part of most plans that affect the public domain. Why is this so? Part of the reason is legislative. The National Environmental Protection Act of 1969 (NEPA), and the avalanche of court decisions that followed in its wake, fundamentally affected the activities of most federal agencies. Its primary purpose is to encourage full disclosure of the environmental consequences of proposed major federal actions, thus alerting the government and public to the environmental risks involved. NEPA spawned and is still spawning a host of offspring in state and local governments across the nation. The California Environmental Quality Act (CEQA), enacted in 1970, is the oldest and one of the most extensive of the state programs.

Viewed in a larger context, NEPA, CEQA, and other environmental quality legistation can be seen as a natural manifestation of the three major changes in awareness identified earlier. Awareness of new publics, negative environmental effects, and resource constraints, moreover, can be viewed in an even larger context as components in a developing systemic view of the world. Resource inputs (now recognized as subject to severe constraints)

are transformed through man's economic processes to outputs (many of which are now recognized as environmentally detrimental). The outputs in turn affect recipients or publics (now recognized as being far more manifold than earlier conceptions.)

Even though all three elements are incorporated to some degree in existing environmental quality legislation, continued evolution of the environmental assessment process appears likely. We speculate that forthcoming modifications will include at least the following:

(1) A gradual recognition that the inputs as well as the outputs of economic processes contribute to environmental quality problems.

(2) A continued expansion of requirements concerning environmental impact statements, bringing them into closer parity with technology assessment studies.

(3) A continued exploration of ways in which meaningfully to encourage public participation in the planning process.

The first trend was mentioned earlier in context with water-energy relationships. Given the relative newness of the environmental awareness phenomenon, it is not surprising that its theoretical underpinnings are still undergoing considerable change. The establishment of links between biological and economic processes using universal physical principles exemplifies how such underpinnings can be strengthened.[13]

The second apparent trend promises to make the already complex environmental impact reporting process all the more inclusive. From the outset, many people minimized the implications of the new environmental legislation. There was a natural tendency to regard the EQ (environmental quality) objectives as an addendum to entrenched NED (national economic development) objectives. Some organizations, notably the Water Resources Council, seem to have at least equated EQ and NED objectives:[14]

> Plans for the use of the Nation's water and land resources will be directed to improvement in the quality of life through contributions to objectives of national economic development and environmental quality...

However, the sequence of changes since NEPA was enacted suggests something more fundamental is occurring than a simple restructuring of institutional objectives. Decisions of many types, particularly those involving the use

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[13] Georgescu-Roegen, loc. cit.

[14] Water Resources Council, "Principles and Standards for Planning Water and Related Land Resources", Federal Register, September 10, 1973.

of scarce resources, are being subjected to more comprehensive forms of evaluation. Environmental impact reports, in other words, appear to be expanding to resemble more closely technological assessment studies. Cynical observers might attribute this trend to obstructionist tactics of environmental zealots or to the newly-vested interests of EIR consultants. Yet one should be cautious about allowing too narrow an interpretation of events to obscure what otherwise might actually be a genuine cultural reorientation in philosophy toward the environment. Distinguishing clear signals amid the social noise is seldom an easy task.

Technology assessment methodology itself has undergone considerable change and controversy as it has evolved over the last decade. In our last progress report, technology assessment was revealed as an "eclectic amalgam of techniques derived mainly from operations research and systems analysis and, therefore, basking in a borrowed glory because of their prestigious heritage in defense and space management."[15] Most of the discipline's applications have centered on narrowly-construed problems in military, public works, or business domains. All too often weighty conclusions are supported on a fragile base of deceptively precise benefit-cost calculations. The failure of such studies to inquire about wider social costs and benefits and their incidence on various publics sometimes leads to unfortunate effects, including popular backlashes against engineers, scientists, and public officials.

Experience with the earlier generation of technology assessment efforts has prompted some of the more perceptive students of technology introduction problems to reconsider their analytical approaches. A more mature approach appears to be emerging. For one thing, the assumptions underlying the discipline are becoming more explicit. Dr. J.F. Coates, a member of the Office of Technology Assessment, outlines six basic assumptions:[16]

- Technology assessment is a policy tool.
- Technology assessment is likely to be iterative and part of an interlocking set of studies.
- New technological knowledge creates new ignorance.
- A major policy need is the organization of certainty and uncertainty to define effective strategies and tactics for managing any particular technology.

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[15] Ida R. Hoos, Special Study No. 5: "Utilization and Assessment of Remote Sensing Data", Annual Progress Report under NASA Grant NGL 05-003-404, Space Sciences Laboratory, University of California, Berkeley, 1 May 1975, pp. 9-56 - 9-57.

[16] Joseph F. Coates, "Some Methods and Techniques for Comprehensive Impact Assessment", Technological Forecasting and Social Change, 6, (1974), p. 341.

- More information and analysis, rather than less, promotes better decisions.

- In the long range, indirect and unanticipated effects of a technology are often more significant than the immediate or planned consequences.

Secondly, there is a growing appreciation of the interrelated nature of public policy issues. Local and national problems concerning energy, diminishing resources, and pollution of air, water, and soil intertwine with global crises concerning armaments, food, population, and capital formation. A third shift concerns disenchantment with traditional quantifications:

> "Unhappy clashes with aroused groups of ecologists have proved that when a dam is being proposed, kingfishers may have as much political clout as kilowatts. How do you apply cost-benefit analysis to kingfishers? ... In the long run the entire Cartesian assumption (that there are measurable and incommensurable quantities) must be abandoned for recognition that quantity is only one of the qualities and that all decisions, including the quantitative, are inherently qualitative."[17]

Finally, there has been a realization that search for a single method for carrying out assessments has been misguided:

> "The broad category of systems analysis is likely to be the central theme in any assessment. But there is no general method, methodology, or technique yet developed for conducting a technology assessment."[18]

If nothing else, continuing maturation of the technological assessment approach has produced a new humility regarding the interaction of technology and the complex systems that encompass man, society, and the environment. Increasingly, technological assessment is viewed as a means of obtaining <u>some</u> insight about the application of technology to <u>some</u> elements of such systems. Comprehensiveness is impossible; routinized approaches to different problems are unrealistic. A well-conceived technological assessment may overcome the obvious limitations of a narrowly-defined EIR study or an overly-precise benefit-cost analysis, but it too will have limitations. Nonetheless, an improved understanding of various technologies and their effect on complex systems is necessary to avoid in the future many of the problems and mistakes of the past. While recognizing their imperfections, we have little choice but to attempt assessments of technology.

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[17] Lynn White, Jr., "Technology Assessment from the Stance of a Medieval Historian", <u>Technological Forecasting and Social Change</u>, 6, (1974), p. 360.

[18] M.J. Cetron and B. Bartocha (eds.), <u>Technology Assessment in a Dynamic Environment</u>, Gordon and Breach, New York, 1973, p. 285.

Changes in attitudes toward public participation accompany the other apparent trends in the environmental assessment process. NEPA, conceived primarily to promote better articulation of trade-offs between economic and environmental factors in environmental decision-making, does not deal specifically with the public participation issue. Subsequent policy statements and local legislation have generally been responsible for interjecting public participation concerns into the environmental and resources management areas. The Water Resources Council, in its "Principles and Standards for Planning Water and Related Land Resources" of 1973, deals directly with public participation issues. The document acknowledges the importance of soliciting public opinion early in the planning process and of maintaining open public communication channels throughout. The WRC efforts are among those canonized as part of Environmental Protection Agency rules governing public participation in water resources decision-making.[19]

Terminology is an important key to understanding what is meant by "public participation". Obviously, two terms are involved here. "Public" has several generally accepted meanings, ranging from "everybody" to unstructured associations of individuals with certain interests in common. An Army Corps of Engineers document divides the "effective publics"--i.e., action bodies--of water resources decision-makers into interested organized groups and interested individuals.[20] Among the groups identified are conservation and environmental groups, sportsman groups, civic organizations and service clubs, and professional organizations. "Participation", the second critical concept, also has a range of meanings, extending from "cards and letters" advice to actual involvement in plan development. The Corps of Engineers, for example, describes public participation as a continuous two-way communication process designed to: (1) promote full public understanding, (2) keep the public fully informed, and (3) actively to solicit opinions, perceptions, and needs from all concerned citizens.[21]

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[19] Adam Clarke Davis, Jill Anderson, and Richard T. Gough, Alternative Information and Interaction Approaches to Public Participation in Water Resources Decision Making: A State of the Arts Report, Water Resources Research Institute of North Carolina, April 1975, p. 4.

[20] Charles W. Dahlgren, Public Participation in Water Resources Planning: A Multi-Media Course, Professional Development Paper 72-1, Institute for Water Resources, Department of the Army, Corps of Engineers, April 1972.

[21] B.H. Dodge, "Achieving Public Involvement in Corps of Engineers Water Resources Planning", Water Resources Bulletin, June 1973, p. 448.

A recent review of public participation in 45 water resources projects showed that the public hearing was by far the most frequently used technique for involving the public in decision-making processes.[22] Other approaches included task forces, committees, advisory boards, workshops, newsletters, surveys, and various combinations of these techniques. Although some of these methods encourage greater public involvement, they usually mean a corresponding increase in agency time, money, and personnel costs. In addition, experimentation with different participation processes is often inhibited by legal requirements that public hearings be held.

Limitations of the public hearing process are well known: notification of the hearing's time and place, domination of the proceedings by vested interests and agency experts, limited opportunity for informed involvement by interested individuals, and so forth. Public apathy is another barrier often encountered in the public hearing process. The problem of encouraging meaningful involvement often splits into two subproblems: first, how to arouse citizen concern, and second, how to organize that concern. In nearly all public participation processes the number of involved people will be a minuscule percentage of the total possible public. Also, there is the problem of evaluation. Public participation activities are notoriously difficult to evaluate. Simple quantification of the number of speakers and their comments is rarely sufficient to evaluate a process that may produce results extending over many years.

Observation over the past year of numerous public hearings--mostly related to water resources agencies--has demonstrated to us that California agencies are not exempt from the usual set of difficulties that afflict public participation processes. In addition to the foregoing limitations, we have noticed a tendency for the hearing publics to polarize into two camps consisting of "land users" (those who control the land for agriculture, industry, or development purposes) and "non-land users" (those who exercise little or no direct control over the land). This polarity has been documented elsewhere.[23] Nationally, the ratio between non-land users and land users has been estimated at 9 to 1. The non-land user group has tended to become the one which initiated the request for land-use planning and regulation, while the land user group is often identified as trying to channel efforts away from planning and regulation into programs incorporating economic incentive.

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[22] Davis, _et al._, _op. cit._, p. iv.

[23] William H. Schmidtman, "The Role of the Concerned Citizen", in _The Grass Roots and Water Resources Management_, _op. cit._, p. 143.

Despite the generous supply of problems relating to public hearings and participation, we have noticed some encouraging signs possibly reflecting the changing nature of water resources management in California. One example concerns the Army Corps hearings concerning Section 404 regulations. There, the State of California went on record along with non-land user groups as generally supporting the Corps proposals.[24] This was in direct contrast to testimony from public officials representing western states (Washington, Oregon, Utah, and Arizona) as well as those representing state agencies at a companion hearing in Omaha, Nebraska. Another example concerns the planning process employed by the California DWR in developing its Water Action Plan. We have already described how the new plan is being built on a base of public testimony from an iterated series of area-specific hearings held throughout the state. Equally important, it seems to us, is the Department's recognition and implementation of means other than the public hearing for gathering knowledgeable inputs to its planning processes. A splendid example of this has been the creation of the California Water Advisory Panel, an informal group of eight distinguished members representing diverse points of view.[25] Other special panels and workshops are planned in the future.

As detailed elsewhere in this report, remote sensing is potentially one of the best means of presenting, to either an advisory panel or to those attending a public hearing an unbiased view of the land and water resources of an area and of explaining proposed action with respect to these resources.

5.4 CONCLUSIONS AND FUTURE PLANS

The foregoing sections have surveyed the current socio-economic landscape of water resource management issues, especially as they pertain to California. A great many changes in the resources management domain are becoming evident, some of them fostered by the favorable climate of candor in Sacramento. Several streams of awareness born in the 1960's and the early 1970's--of multiple publics, of negative environmental effects, and of resource constraints--appear to be converging on a national and global scale. In California and elsewhere, this convergence often means that old assumptions are now exposed to challenge. With respect to water resources management in California, we think several early results of this phenomenon can be identified:

(1) A changing emphasis from resource development to resource management.

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[24] Testimony of Larry E. Moss, Deputy Secretary for the Resources Agency, State of California, Hearings re Corps of Engineers Permits for Activities in Navigable Waters or Ocean Waters, San Bruno, California, 12 September 1975, pp. 25-34.

[25] Members of the panel are: Messrs. Harvey O. Banks, William E. Warne, and William R. Gianelli, former Directors of the Department of Water Resources; Ms. Mary Ann Eriksen, Southern California Representative of the Sierra Club; Mr. Tom Graff, Regional Counsel for the Environmental Defense Fund; Mr. Bill Press, Executive Director of the Planning and Conservation League; Dr. Tim Wallace, Director of the Department of Food and Agriculture; and Ms. Versia Metcalf, International Representative of the United Auto Workers.

(2) An increasing emphasis on comprehensiveness in water resources planning, including:
   (a) An attempt to increase meaningful public participation;
   (b) An attempt to relate to other functional areas;
   (c) An attempt to integrate more effectively with other jurisdictional areas.

(3) A growing appreciation of the need for anticipating and assessing the environmental effects of new projects, programs, and policies, coupled with a growing awareness of the inherent limitations of environmental assessment studies.

Within the framework of assessing the ultimate usefulness of remote sensing technology to water resource management, the Social Sciences Group will continue to study the pertinent issues, policies and methodologies. It is already clear that certain issues will continue to demand attention. Some are specific to regions, such as protection of the Delta. Here, three of the basic research interests reported previously in this report will predominate, viz., federal-state jurisdictions over water, environmental impact as a social assessment process, and what constitutes bona fide public participation in this process.

Some of the issues have to do with policy and in this respect the state-federal relationship will be of paramount importance. During the past year we have witnessed the drafting of a memorandum of understanding between the State Department of Water Resources, the State Water Resources Control Board, and the U.S. Bureau of Reclamation. The proposal was intended to clarify, stipulate, and thus eliminate the conflicts as to procedures for coordination of water rights, environmental impact statement review, and federal project authorization. The State maintains an official stance of willing cooperation This was clearly indicated at the September 1975 hearings held by the U.S. Army Corps of Engineers.

During the coming months, the Social Sciences Group will direct some of its research effort to the socio-economic ramifications of the Army Corps' increase in authority. These promise to be considerable, as is already evidenced in the effects of their activities vis-a-vis inland waterways. According to a report released on 26 November 1975 by the General Accounting Office, the Corps has favored a policy of expansion of the system. Costs of development and maintenance, close to $3 billion, have been borne by taxing the general public. Neither commercial nor recreational traffic has been required to pay fees that would help recover some of the construction costs. If there were a user charge, passed along from barge carriers to shippers or receivers, there is the likelihood of diversion to other traffic modes, with potential energy savings anticipated. As with changes in California water pricing policy, a shift here could significantly alter user patterns. There are, moreover, environmental considerations that might, if given due regard, discourage further development of the inland waterway system,unacceptable amounts of damage having been attributed to commercial use.

Consistent with our plan to study federal-state interactions, we can foresee that the expanded responsibility of the Corps will create many situations of vital concern to the citizens of California with respect to their water resources. We can reasonably predict that there may be a pressing need for new models of public planning.

Having already reviewed considerable testimony gathered at public hearings, we can discern the polarizations that seem to occur. There are the jurisdictional struggles between the Federal, State, and local levels. There is also dissonance between private interests and the public good. We deem it important to assess realistically both the inputs and outcomes of citizen participation. It becomes increasingly important to consider alternative methods and strategies for public resource management. While technology assessment is an important step, and cost-effectiveness calculation a valuable tool, there is the larger framework into which they must be integrated.

A model which offers promise has been developed for resolving disputes over such matters as offshore oil drilling, river basin development, strip mining, and location of power plants. Using mediation procedures similar to those used in labor disputes, the Office of Environmental Mediation at the University of Washington in Seattle achieved successful mediation of a 15-year controversy, highlighted by bitter confrontations, over plans to build a dam on the Snoqualmie River in the Pacific Northwest. The problems are classic in their characteristics and epic in proportion. The Valley, always subject to flooding, had in 1959 experienced one which was particularly devastating. Land along three forks of the river was inundated; two towns were heavily damaged and crops in the fertile farmland of the lower valley washed away. By 1960, the Army Corps of Engineers had begun drafting plans for a dam and the battle lines were drawn. Conflicting interests followed customary lines, with support coming from developers desiring a flood-protected valley and farmers welcoming protection against the annual inundations. Opposition came from conservationists and even urban dwellers who valued wilderness areas and who feared that the dam would bring suburban blight to the area. Resolution came about through an innovative use of mediation techniques derived from labor-management experience. Seven months of sensitive negotiations led to decisions acceptable to the diverse interests. It is our intent to investigate the utility of applying this model of decision-making to some of California's present and future water management decisions.

As we review the various methodologies for technology assessment and environmental impact, we plan to continue our exploration of the activities and decision processes that interface with water resources management. This sort of peripheral vision is essential if we are to discover and assess how remote sensing technology can be employed to enhance the decision environments of resource management agencies. As mentioned earlier, it is <u>combinations</u> of users, uses, and data sources that will produce many of the future remote sensing applications. In this context we expect to include in forthcoming work special investigations in the land and energy areas, especially. Current work in the

Berkeley Remote Sensing Research Program concerning the DWR irrigated agriculture inventories is an excellent example of an application in which our socio-economic exploration will continue to be of value.

The last item on our list of forthcoming activities concerns NASA's present program to document more fully operational and near-operational LANDSAT applications. In addition to our continued exploration of the socio-economic landscape surrounding the management of California water resource management issues, we plan to give special consideration to those circumstances--both within and outside the water resources environment--where satellite remote sensing can be identified as now or soon contributing valuable information to resources management decision-making. This task will be integrated with parallel efforts on the technical side of remote sensing applications performed by investigators within the Integrated Group. Hopefully, we will be able to include testimony by the users themselves regarding the application of remote sensing technology to their decision processes. In the final analysis, is it not the quality of resource management decisions, and their societal consequences, that we are interested in improving?

CHAPTER 6

SPECIAL STUDIES

CHAPTER 6

SPECIAL STUDIES

Special Study No. 1: Video Polarizer for Remote Sensing of Earth Resources

Co-Investigators: K. L. Coulson and R. L. Walraven
Davis Campus

During the past year an instrumentation system capable of sensing and displaying the intensity and polarization information in natural landscape scenes has been built. The system, which we have termed a video polarizer, consists of a three-vidicon television array in combination with appropriate signal processing electronics and a color television monitor. It has been used successfully for the acquisition and display of simultaneous intensity and polarization information in natural landscape scenes on the UC Davis campus.

A schematic diagram of the basic components of the video polarizer is given in Fig. 1. Three black-and-white vidicon cameras are mounted in a parallel orientation on a common mount. Polarizing filters are inserted in the optical path in front of the lenses of two of the cameras. If the stream of radiation from a point in the scene is described by an intensity, I_0, a degree of linear polarization, P, and an angle of the plane of polarization, χ, then after passing through a linear polarizer, the intensity of the stream of radiation will be

$$I = \frac{1}{2} I_0 [1 + P \, \mathrm{Cos} 2(\theta - \chi)]$$

where θ is the angle of the principal axis of the polarizer. If the polarizer in

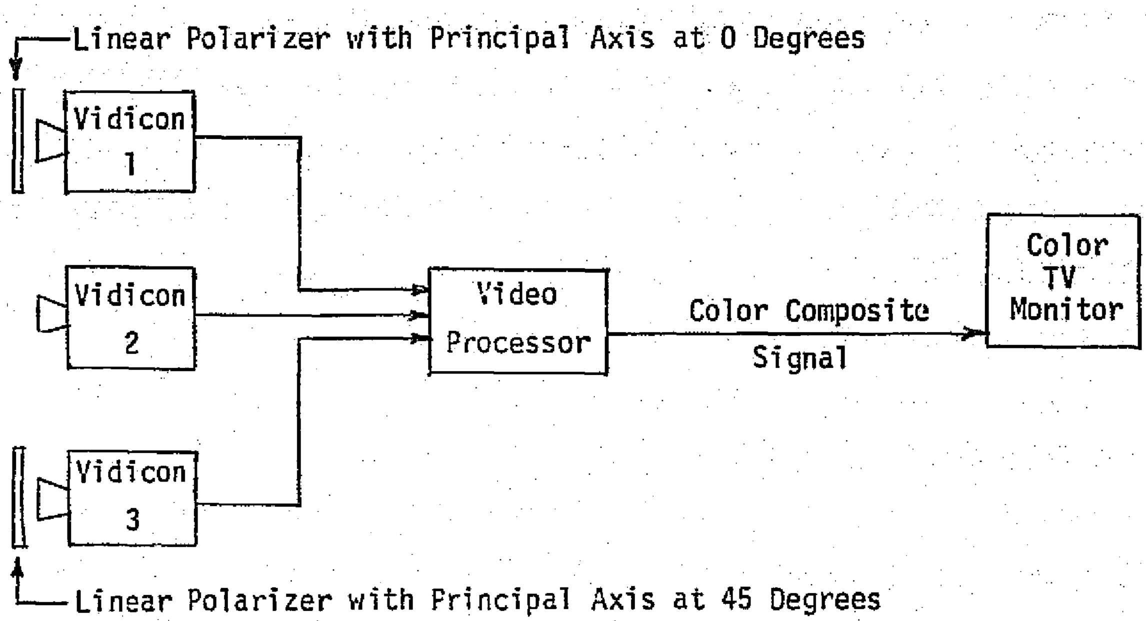


Figure 1. Schematic deagram of the present video polarizer system.

front of camera number 1 is set such that $\theta_1 = 0°$ and that in front of number 3 has $\theta_3 = 45°$, then the intensity of radiation entering the lenses of the cameras is, respectively,

$$I_1 = \frac{1}{2} I_o [1 + P \operatorname{Cos} 2\chi]$$

$$I_2 = I_o$$

$$I_3 = \frac{1}{2} I_o [1 + P \sin 2\chi]$$

From these three quantities we can determine I_o, P, and χ. For the present video polarizer, the three black-and-white signals are combined by a special processor into a single color composite signal which contains the intensity information as the black-and-white brightness component and the polarization information as the color component. Saturation of the color indicates degree of linear polarization, and hue of color indicates the angle of the plane of polarization. Thus the system creates an image containing all of the intensity and polarization information from the original scene in real time on a color television monitor.

Some typical results obtained with the video polarizer are shown in the two photos of the face of the television monitor in Fig. 2. Although the photos are somewhat crude, they do show the effect of polarization of light from the scene. The two images were taken within a few seconds of each other, the only difference being a change of the angle of the polarizers in front of two of the cameras. It should be remarked that parallax problems due to the physical separation of the cameras cause multiple images of nearby objects, and use of a camera with a focal plane shutter to photograph the television monitor produced the appearance of diagonal shadows in the photos. However, if these difficulties are ignored and the photos are compared, differences in both hue and saturation of colors in the photos can be seen.

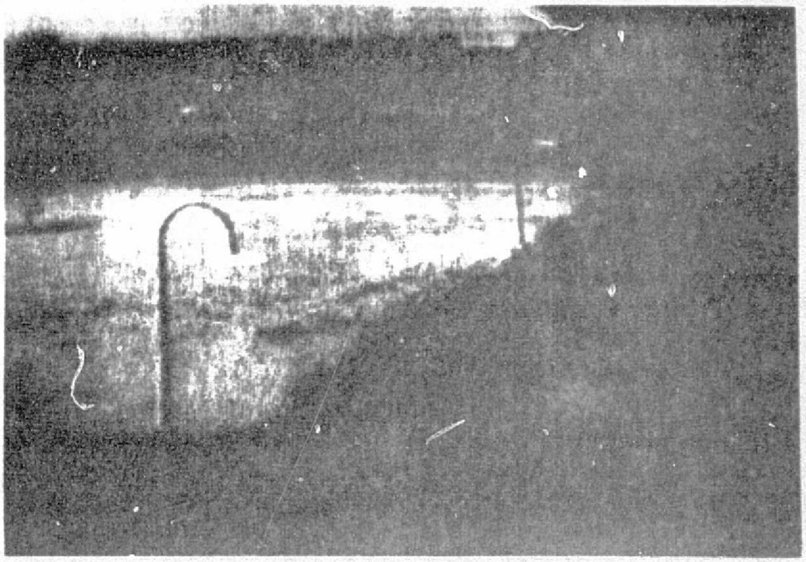
For instance, the feature which exhibits the highest degree of polarization is the asphalt-covered bicycle path in the lower central section of the photos. A change of orientation of the polarizers produces a change of the hue of the path from reddish to a greenish color, while relatively little change occurs

elsewhere in the photos. In fact, in the absence of polarization, a given feature should ideally be unchanged, but with imperfections in the system this may not be achieved completely.

Returning to the asphalt surface, a small area of more highly saturated color appears in both photos. This is produced by the surface of the asphalt being wet. A few minutes before the photos were taken, water was poured on this area, and at the time of the photos the surface was still wet. There was a small amount of standing water in the area. The increased saturation of color was produced by an enhancement of the degree of polarization of the light reflected from the water and the wet surface of the asphalt.

A careful inspection of other features in the photos, including the sky, natural vegetation in the background, and the large area of grass, shows more subtle differences of color between the photos. This also is an effect of polarization, although at this particular angle of incidence of sunlight the polarization is not high.

It is anticipated that this, or a similar, system will be a valuable aid in discriminating among various types of surfaces in studies of earth resources. For instance, it is known that various types of agricultural crops have different polarization characteristics, and the polarization of light reflected from a given bare soil is a function of the amount of surface moisture the soil contains. There are many other polarization features in nautral scenes, some of which are still not known, which have potential for purposes of remote sensing. The present system has the capability of capitalizing on those features.



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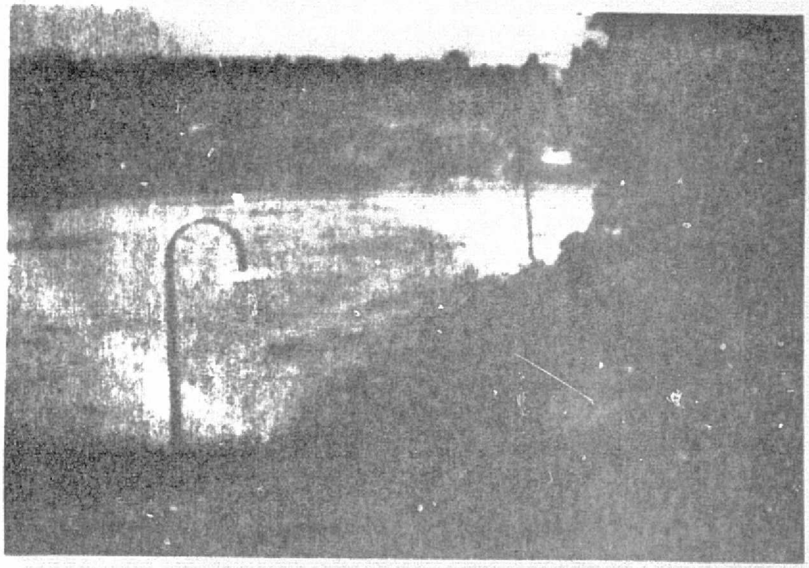

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Figure 2. A and B--two photos of the face of the television monitor for different orientations of polarizers in front of the television cameras.

Special Study No. 2: On the Frequency Weighted Least-Squares Design of Finite Duration Filters*

Co-Investigator: V. R. Algazi, Davis Campus

Contributor: Minsoo Suk, Davis Campus

Abstract: The frequency weighted least-square design of finite-duration filter, in one- and two-dimensions, continuous and discrete is considered. Some new theoretical results and some practical design techniques for conventional and unconventional filters are presented. In some cases optimum discrete filters can be found conventionaly by matrix inversion. In many cases a simple, iterative approximation technique using FFT can be used to carry out the design or to adjust the frequency response filters.

I. Introduction

In the design of finite-duration filters which approximate some desired frequency response, the designer has generally to contend with different approximation requirements for different regions of the frequency spectrum. For one-dimensional sampled data filters with periodic sampling (finite-duration impulse response (FIR) digital filters), a number of design techniques have been developed which achieve these design objectives (see (25)-(27) for excellent summaries). A common and simple technique using data windows approaches the problem in a two step fashion. A trigonometric approximation of the desired frequency response is first obtained. This approximation is optimum in the least-square sense. Then one of several finite duration windows with good frequency concentration properties is used to modify the previous design and to reduce the unwanted effects of the Gibbs phenomenon in parts of the frequency range. One specially important data window has been derived analytically in the fundamental work of Slepian and Pollak who established the optimal frequency concentration property of one of the prolate spheroidal functions of zero order (1). The related Kaiser Window (2) is commonly and successfully used in the design of FIR digital filters (3). We consider in this paper an alternate analytic approach to the design of one-and two-dimensional filters and windows of finite duration. This approach differs in philosophy and in detail from previous work in the sense that primary emphasis is given to the constraint of a finite duration and only secondarily to the additional conditions of a continuous or discrete

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filter or to the uniformity of the sampling grid. A frequency weighted least-square approximation measure is used which incorporates, from the start, different approximation requirements in different parts of the frequency spectrum. For low-pass continuous filters, this approach leads naturally to solutions in terms of all prolate spheroidal functions of zero order and relates low-pass filters to spectral windows. The motivation for this work is in applications to image processing and encoding for which the two-dimensional sampling grid, by choice or by constraint, may be nonrectangular and are in fact often highly nonuniform. Thus attention will be given to continuous filters with finite duration as well as to nonuniform sampling problems. Although most of the results and examples in this paper are one-dimensional, the extension to two dimensions is discussed and a simple illustrative example is presented.

The objectives of this paper range from the theoretical, the establishment of the mathematical equations for filters optimal in a very specific sense, to the very practical, in providing design techniques which can be used for less conventional design problems than the well documented design of one-dimensional low-pass, high-pass, and bandpass digital filters. Of special importance is the fact that the techniques presented extend naturally to two dimensions.

II. Transform Domain Limitations of Finite-Duration[1] Functions

The frequency behavior of finite-duration functions is constrained by fundamental limitations. Several transform domain limitations of finite-duration functions have been established throughout the years. They are known as generalized time-bandwidth uncertainty relations [4]–[6].

Let us define the measure of the time spread of $g(t)$ by

$$\alpha^2 = \frac{\int_{-\infty}^{\infty} w_\alpha(t)|g(t)|^2\, dt}{\int_{-\infty}^{\infty} |g(t)|^2\, dt} \tag{1}$$

and the measure of the frequency spread of its Fourier transform $G(f)$ by

$$\beta^2 = \frac{\int_{-\infty}^{\infty} W_\beta(f)|G(f)|^2\, df}{\int_{-\infty}^{\infty} |G(f)|^2\, df}. \tag{2}$$

The most familiar form of the uncertainty principle states that if we assign a time weight of $w_\alpha(t) = (t - t_0)^2$ and frequency weight of $W_\beta(f) = (f - f_0)^2$, then for any choice of t_0 and f_0, $\alpha\beta \geq \pi$.

Analytical techniques have been applied to the design of a family of time functions or windows with optimal properties [1]. Among a set of duration limited window functions, i.e., among a set of window functions $h(t)$ such that $h(t) = 0$ for $|t| > T/2$, an optimal window function $h_0(t)$ which minimizes the frequency spread β^2 defined above can be shown to be

$$h_0(t) = \begin{cases} \phi_0(t), & |t| \leq T/2 \\ 0, & \text{otherwise} \end{cases}$$

[1] In general, the duration does not necessarily refer to time, it could be spatial support such as in image processing. For convenience we shall refer to all such cases as finite duration.

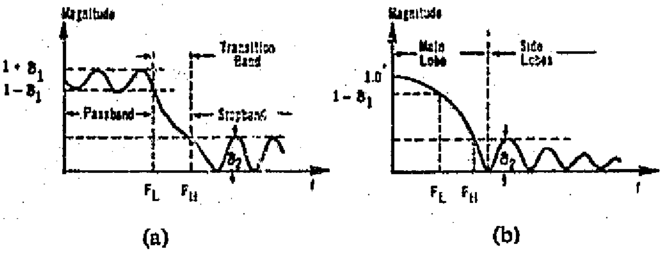


Fig. 1. Magnitude-square characteristics for low-pass filter and window function. (a) Low-pass filter. (b) Window function.

where $\phi_0(t)$ is the eigenfunction corresponding to the largest eigenvalue λ_0 of the integral equation

$$\int_{-T/2}^{T/2} \frac{\sin 2\pi f_c(t - \tau)}{\pi(t - \tau)} \phi_n(\tau)\, d\tau = \lambda_n \phi_n(t). \tag{3}$$

The frequency weight $W_\beta(f)$ which is used here to define frequency spread β^2 is given by

$$W_\beta(f) = \begin{cases} 0, & |f| \leq f_c \\ 1, & \text{otherwise.} \end{cases}$$

The $\phi_n(t)$'s are the prolate spheroidal functions of zero order and $\phi_0(t)$ is closely approximated by Kaiser windows [2]. These prolate spheroidal functions have an important theoretical role in our work as we shall see in the following sections.

III. Frequency Domain Description of Filters and Data Windows

Typical design parameters of interest for filters are the deviation of the frequency response from an ideal response within passband(s), the amount of attenuation in stopband(s), and the width of transition band(s) (see Fig. 1). In a frequency weighted least-square design approach we shall recognize different objectives by assigning different relative weights to errors in different frequency ranges. Formally, we consider $H_i(f)$ to be an ideal frequency response to be approximated. Then in general, the model $h_i(t)$ has to be defined for all time t. The optimal approximation (in the weighted least-square sense) $h_0(t)$ which is restricted to $|t| \leq T/2$ is $h_a(t)$ which minimizes

$$I = \int_{-\infty}^{\infty} \{w(t) * [h_i(t) - h_a(t)]\}^2\, dt \tag{4}$$

or equivalently, by Parseval's theorem

$$I = \int_{-\infty}^{\infty} |W(f)|^2 |H_i(f) - H_a(f)|^2\, df \tag{5}$$

where we require $h_a(t) = 0$ for $|t| > T/2$. The purpose of introducing $w(t)$ is to provide an appropriate weight in the frequency domain as shown in (5).

Although results can be obtained for an arbitrary weighting function $|W(f)|^2$, we shall emphasize, in this paper, the simplest such weight which accommodates different objectives and specifications in a passband, a transition band, and a stopband of a low-pass filter.

Consider an arbitrary ideal low-pass frequency characteristic $H_i(f)$ of a continuous filter such that

$$H_i(f) \equiv 0, \qquad |f| > f_c \tag{6}$$

and an error frequency weight

$$|W(f)|^2 = \begin{cases} 1, & |f| \le f_0 \\ A, & \text{otherwise.} \end{cases} \tag{7}$$

Without loss of generality the weight is set equal to 1 in the passband. In the stopband $|f| > f_0$ we use a weight A, which may be very large. The region $f_c < |f| \le f_0$ is the transition band, in the sense that we would ideally like to get zero response, but we do not assign a high weight to the corresponding errors.

In the case of window functions, we are mainly concerned with the concentration of energy in the main lobe and with the size of the side lobes. Thus for window functions the only frequency requirement is a maximum rejection specification in the stopband. This objective can be achieved using a weighted least-square approach by approximating an ideal low-pass filter as in (6) and by using a very large value of A in (7). It will be shown that, in general, as $A \to \infty$, $h_a(t) \simeq \phi_0(t)$, the optimal window, solution of (3).[2]

IV. Weighted Least-Square Design of Finite-Duration Continuous Filters (One-Dimensional)

We now consider the minimization of the weighted least-square integral (4) by proper choice of the finite-duration filter $h_a(t)$. Before we proceed with the mathematics of the problem, a comment is needed on the physical significance and potential use of finite-duration continuous filters since in general, they cannot be readily implemented by physical devices.[3] Still, this continuous filter is useful in applications such as interpolation and change of sampling rates. In addition, often we could obtain FIR digital filters with comparable frequency characteristics by periodic sampling of continuous filters.

The determination of $h_a(t)$ in (4), is a classical minimization problem which leads to the well-known orthogonality principle or projection theorem [7]. It can be shown that the optimal filter $h_0(t)$ satisfies a Fredholm integral equation of the first kind:

$$Q(t) = \int_{-T/2}^{T/2} R(t-\alpha)h_0(\alpha)\,d\alpha, \qquad |t| \le T/2 \tag{8}$$

where

$$R(\alpha - \beta) = \int_{-\infty}^{\infty} w(t-\alpha)w(t-\beta)\,dt$$

and

$$Q(t) = \int_{-\infty}^{\infty} R(t-\alpha)h_i(\alpha)\,d\alpha.$$

Thus $R(t)$ and $Q(t)$ are known for all t. For completeness, these results are derived briefly in the Appendix.

In general, this equation is difficult to solve, and the solution is given in the form of a series expansion [8], [9].

For the frequency weight of (7) we have

$$R(t) = A\delta(t) - (A-1)\frac{\sin 2\pi f_0 t}{\pi t} \tag{9}$$

and (8) becomes

$$Q(t) = Ah_0(t) - (A-1)\int_{-T/2}^{T/2} \frac{\sin 2\pi f_0(t-\alpha)}{\pi(t-\alpha)} h_0(\alpha)\,d\alpha, \qquad |t| \le T/2. \tag{10}$$

We rewrite (10) as

$$h_0(t) = \frac{1}{A}Q(t) + \frac{A-1}{A}\int_{-T/2}^{T/2} \frac{\sin 2\pi f_0(t-\alpha)}{\pi(t-\alpha)} h_0(\alpha)\,d\alpha, \qquad |t| \le T/2 \tag{11}$$

and (11) is a Fredholm integral equation of the second kind.

Since the kernel of the integral equation

$$K(t,\alpha) = \frac{\sin 2\pi f_0(t-\alpha)}{\pi(t-\alpha)} \tag{12}$$

is positive definite, it is well known that [8], [9], for the homogeneous equation,

$$\int_{-T/2}^{T/2} K(t,\alpha)\phi_k(\alpha)\,d\alpha = \lambda_k\phi_k(t), \qquad |t| \le T/2 \tag{13}$$

the orthonormal set of eigenfunctions $\{\phi_k(t)\}$ forms a complete orthonormal set over $[-T/2,T/2]$, and every function $g(t)$ square integrable over $[-T/2,T/2]$ admits the expansion, convergent in the mean

$$g(t) = \lim_{k\to\infty}\sum_{k=0}^{K} g_k\phi_k(t) \tag{14}$$

where

$$g_k = \int_{-T/2}^{T/2} g(t)\phi_k^*(t)\,dt. \tag{15}$$

Also, according to Mercer's theorem [8], the kernel $K(t,\alpha)$ can be expanded in the series

$$K(t,\alpha) = \sum_{r=0}^{\infty} \lambda_r\phi_r(t)\phi_r(\alpha) \tag{16}$$

where the convergence is uniform for $-T/2 \le t, \alpha \le T/2$. Applying these results to the problem at hand we can expand $Q(t)$ as

$$Q(t) = \sum_{r=0}^{\infty} q_r\phi_r(t), \qquad |t| \le T/2 \tag{17}$$

where

$$q_r = \int_{-T/2}^{T/2} Q(t)\phi_r^*(t)\,dt. \tag{18}$$

[2] For large A, the optimal solution of (11), $h_0(t)$, will in general be proportional to $\phi_0(t)$, the first eigenfunction of (13). To see this result we note that as $A \to \infty$ the relative contributions of $\phi_k(t)$ and $\phi_0(t)$ to $h_0(t)$ are from (19) and (20), $(h_k/h_0) = \varepsilon(q_k/q_0(1-\lambda_k))$, q_k and q_0 as in (17), with $\varepsilon = 1 - \lambda_0$, the fraction of energy of $\phi_0(t)$ in the stopband, generally extremely small. Thus in most cases, since $(q_k/q_0(1-\lambda_k))$ is finite for $k \ne 0$, all h_k's, $k \ne 0$, will be very small and $h_0(t)$ is roughly proportional to $\phi_0(t)$.

[3] Note that such continuous filters can be approximated by a combination of tapped delay lines, and active or passive lumped circuits.

Then the integral equation (10) can be reduced to the problem of finding the expansion coefficients h_k of $h_0(t)$ where $h_0(t)$ is given by

$$h_0(t) = \sum_{k=0}^{\infty} h_k \phi_k(t), \qquad |t| \le T/2. \tag{19}$$

It is easy to show that h_k is given by

$$h_k = \frac{q_k}{A - (A-1)\lambda_k}. \tag{20}$$

Note that for the kernel of (12), the integral equation (13) reduces to (3).

Slepian and Pollak have shown that the eigenvalues λ_k's of (13) are real and positive [1]. Let the λ_k's be ordered as $\lambda_0 > \lambda_1 > \cdots$. If the λ_k's decrease rapidly with k, then we need only the first few terms to approximate $h_0(t)$.[4] The eigenvalues λ_k's and the eigenfunctions $\phi_k(t)$'s are tabulated in the literature as a function of the parameter $c = \pi f_0 T$, and are known as prolate spheroidal functions. For small values of c ($c \le 8$), the functions are tabulated in terms of Legendre polynomials [10], [11], and for large values of c, asymptotic expressions for λ_k's and $\phi_k(t)$'s are given in Slepian [12].

Iterative Determination of $h_0(t)$

The solution of (11) in terms of eigenvalues and eigenfunctions is practically useful only if the solutions of the homogeneous equations (13) are known in closed form or tabulated. There are very few such cases.

Another approach to the solution of the integral equation without solving eigenvalues and eigenfunctions is the Neumann series approach. The Neumann series solution is an iterative approach in which an approximation to $h_0(t)$ used in the integral on the right-hand side of (11) generates the next approximate solution. Let the kth approximation to $h_0(t)$ be $\hat{h}_k(t)$, then the $(k+1)$th approximation $\hat{h}_{k+1}(t)$ is given by

$$\hat{h}_{k+1}(t) = \frac{1}{A} Q(t) + \frac{A-1}{A} \int_{-T/2}^{T/2} \frac{\sin 2\pi f_0(t-\alpha)}{\pi(t-\alpha)} \hat{h}_k(\alpha)\, d\alpha, \qquad |t| \le T/2. \tag{21}$$

Note that if $f_c \le f_0$ in (7) then $Q(t) = h_i(t)$. Let D_T be a duration limiting operator, and B_{f_0} be a bandlimiting operator, i.e., for any time function $g(t)$, and its Fourier transform $G(f)$

$$D_T g(t) = \begin{cases} g(t), & |t| \le T/2 \\ 0, & \text{otherwise} \end{cases}$$

and

$$B_{f_0} G(f) = \begin{cases} G(f), & |f| \le f_0 \\ 0, & \text{otherwise.} \end{cases}$$

[4] For $c = 8.0$, only 5 terms are used in a series solution, all with even indices, starting with $\phi_0(t)$. The first term neglected $\phi_{10}(t)$ has an eigenvalue $\lambda_{10} = 8.93 \times 10^{-7}$ as compared to $\lambda_0 = 0.999997$. The tabulated values of the λ_k's are taken from [13].

Using this notation, (21) can be rewritten as

$$\hat{h}_{k+1}(t) = D_T\left[\frac{1}{A} h_i(t) + \frac{A-1}{A} B_{f_0}\hat{h}_k(t)\right]. \tag{22}$$

The approximation process successively bandlimits the previous approximation and then duration limits a weighted sum of the model and the bandlimited function $B_{f_0}\hat{h}_k(t)$. For $A = 1$ we immediately get $h_0(t) = D_T h_i(t)$, as expected. As $A \to \infty$ we shall generally obtain[2]

$$h_0(t) = \begin{cases} \phi_0(t), & |t| \le T/2 \\ 0, & \text{otherwise.} \end{cases}$$

Thus the stopband behavior is generally constrained by the behavior of $\phi_0(t)$ for the specific time-bandwidth product $c = \pi f_0 T$. By proper choice of A, one achieves a tradeoff between these two limiting cases for the in-band and stopband behaviors. This intuitively pleasing result and (22) also suggests a very simple approach to the design of FIR digital filters as we shall see later.

The successive approximate solutions will converge to the solution of (11), when $|(A-1)/A|\|K\| < 1$, where $\|K\|$ is the norm of the kernel [9]. Since the specific kernel of (12) is a symmetric Hilbert–Schmidt kernel, at least one of the two numbers $\|K\|$ and $-\|K\|$ is an eigenvalue of the kernel K [9]. It is well known that the eigenvalues of the kernel K of (12) are bounded by 1 [1], therefore the series always converges. However, for many cases of interest, $\|K\|$ is very close to 1 [13], and the convergence is strongly dependent on the value of A.

An Example of Continuous Filter: Design of a Low-Pass Filter

We consider the problem of approximating a low-pass filter with an ideal frequency characteristic

$$H_i(f) = \begin{cases} 1, & |f| \le f_c \\ 0, & \text{otherwise} \end{cases} \tag{23}$$

i.e., a low-pass filter with cutoff frequency f_c, using the frequency weight of (7) with $f_c \le f_0$.

To solve this problem we use here the series solution (19) which requires very few terms.[4] The evaluation of the q_k's of (18) may be done more conveniently using Fourier transform techniques; since $Q(t) = h_i(t)$,

$$\begin{aligned} q_k &= \int_{-T/2}^{T/2} h_i(t)\phi_k(t)\, dt \\ &= \int_{-\infty}^{\infty} H_i^*(f)\Phi_k(f)\, df \\ &= \int_{-f_c}^{f_c} \Phi_k(f)\, df \end{aligned}$$

where

$$\Phi_k(f) = \int_{-T/2}^{T/2} \phi_k(t) e^{-j2\pi f t}\, dt.$$

We chose a value for the time-bandwidth product $c = \pi f_0 T = 8.0$. For that value of c as $A \to \infty$ we obtain for

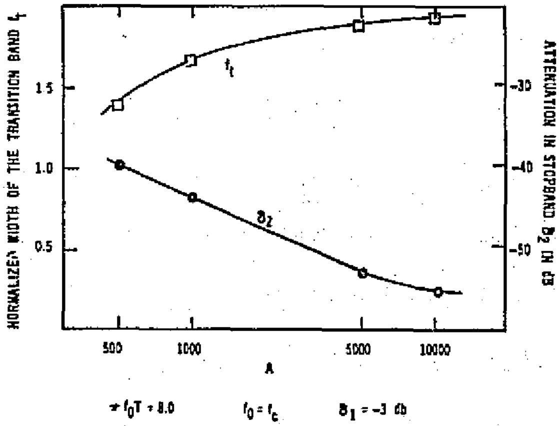


Fig. 2. Effect of parameter A on normalized width of transition band and attenuation in stopband.

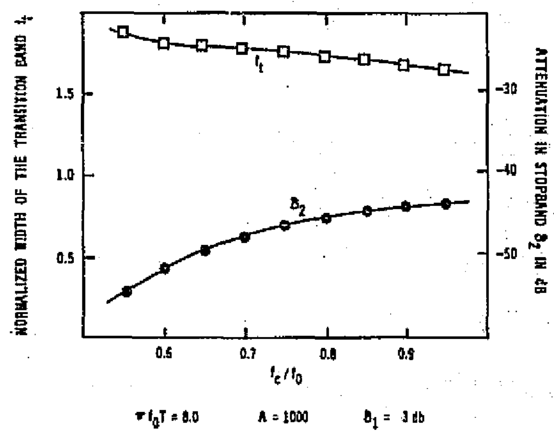


Fig. 3. Effect of parameter f_c/f_0 on normalized width of transition band and attenuation in stopband.

$h_0(t)$ the time limited version of the prolate spheroidal function of zero-order $\phi_0(t)$.

To control the frequency response of the filter we have two parameters available in addition to c. The weight A, which controls principally the attenuation in the stopband and to a lesser extent the transition band, and f_c, the cutoff frequency of the ideal model, which controls principally the transition band.

The effects of A and f_c are shown in Figs. 2 and 3. We have chosen as variables the attenuation in the stopband in decibels and the width of the transition band $f_t = T(F_H - F_L)$, normalized to the reciprocal of the duration. This example illustrates the relation of a continuous low-pass filter to an optimum window. Slepian and Pollak [1] found the window function which gives the highest concentration of energy in the frequency band $|f| \leq f_0$. This window function is the eigenfunction of (13) with the largest eigenvalue. But, as can be seen in (19), to improve the behavior within the passband, one of our objectives, we need to introduce higher order eigenfunctions. The contribution of these higher order eigenfunctions to the frequency response within the passband, and the amount of corresponding tradeoff in the stopband attenuation is related to the value of A and f_c.

Note that the minimum attenuation in the stopband depends on the product $\pi f_0 T$ (time-bandwidth product) and that higher attenuations will be obtained by increasing that product.[5]

This example, using a series expansion approach, is principally of theoretical interest since the prolate spheroidal functions are only tabulated for small values of c. The iterative approach, using the Neumann series, is more generally applicable and will be used to design a two-dimensional filter-interpolator in Section VI.

V. Design of Finite-Duration Discrete Time Filters

Uniformly Spaced Filters[6,7]

These filters are also known as FIR digital filters. For the design of FIR digital filters, we require $h_0(t)$ to be defined on only N uniformly spaced discrete time instants $\{t_0, t_1, \cdots, t_{N-1}\}$ and $h_0(t) = \sum_{k=0}^{N-1} a_k \delta(t - t_k)$. Then the optimal coefficient a_k corresponding to t_k, $k = 0, 1, \cdots, N-1$, is given by a matrix equation

$$Ca = b \tag{24}$$

where a and b are $(N \times 1)$ column vectors and C is an $(N \times N)$ matrix which are defined by

$$b_k = \int_{-\infty}^{\infty} w(t - t_k)[w(t) * h_i(t)]\, dt \tag{25}$$

$$c_{kj} = \int_{-\infty}^{\infty} w(t - t_k) w(t - t_j)\, dt, \qquad k, j = 0, 1, \cdots, N-1. \tag{26}$$

The optimal coefficients a_k's can be determined by solving the matrix equation of (24). Note that the matrix C is a Toeplitz matrix and there exist several efficient algorithms to invert a Toeplitz matrix [15], [16]. Instead of inverting the matrix C, the column vector a can be expressed in terms of the eigenvalues and eigenvectors of the matrix C as mentioned earlier. For the frequency weight

$$|W(f)|^2 = \begin{cases} 1, & |f| \leq f_0 \\ A, & f_0 < |f| \leq f_N \\ 0, & \text{otherwise} \end{cases} \tag{27}$$

where f_N is the Nyquist frequency, these eigenvalues and

[5] The following table indicates approximately the minimum stopband attenuation as a function of $c = \pi f_0 T$.

c/π	attenuation in dB
0.9	−21
1.5	−37
1.8	−42
2.5	−58
3.0	−74
3.5	−87
4.5	−111

[6] See related work by Fleisher [14].

[7] In a recent paper [24] Farden and Scharf approached the design of nonrecursive filters on a statistical basis and proposed a design technique for FIR filters which is essentially a weighted least-square design. In addition to several examples, their paper includes a computer program for the inversion of Toeplitz matrices.

eigenvectors are analogous to the prolate spheroidal functions and have been discussed by Papoulis [17]. Note that we have now $t_{k+1} - t_k = 1/2f_N$. For the frequency weight of (27), as for continuous filters, we can obtain an iterative approximation to a which avoids inverting the matrix C. Let us define

$$g(\alpha) = \int_{-\infty}^{\infty} w(t)w(t-\alpha)\,dt \tag{28}$$

then

$$c_{kj} = g(t_k - t_j) \tag{29}$$

and the Fourier transform $G(f)$ of $g(\alpha)$ is

$$G(f) = |W(f)|^2. \tag{30}$$

We write the matrix C as a sum of two matrices with

$$\begin{aligned} c_{kj} &= \int_{-\infty}^{\infty} |W(f)|^2 e^{j2\pi f(t_k - t_j)}\,df \\ &= A\int_{-f_N}^{f_N} e^{j2\pi f(t_k - t_j)}\,df - (A-1)\int_{-f_0}^{f_0} e^{j2\pi f(t_k - t_j)}\,df \\ &= A\delta_{kj} - (A-1)c_{kj}' \end{aligned} \tag{31}$$

where

$$c_{kj}' = \int_{-f_0}^{f_0} e^{j2\pi f(t_k - t_j)}\,df.$$

Now the matrix equation (24) becomes

$$\begin{aligned} b &= Ca \\ &= (AI - (A-1)C')a \\ &= Aa - (A-1)C'a \end{aligned} \tag{32}$$

or

$$a = \frac{1}{A}b + \frac{A-1}{A}C'a \tag{33}$$

where I is an identity matrix.

Note that when $H_i(f)$ vanishes for $|f| \geq f_0$, we have $b_j = h_i(t_j) \triangleq h_{ij}$. Then the $(k+1)$th approximation $\hat{a}_{k+1}$ of a is given by

$$\hat{a}_{k+1} = \frac{1}{A}h_i + \frac{A-1}{A}C'\hat{a}_k. \tag{34}$$

The successive approximation (34) converges since all the eigenvalues of the matrix C' have magnitude less than 1 [17], [18]. As in the continuous case, these successive approximations can be done very easily, and can be interpreted as applications of successive duration limiting operations and bandlimiting operations using the FFT algorithm.

To see this, let us form a new matrix C'', of order $(2M \times 2M)$, by augmenting the matrix C',

$$C'' = \begin{bmatrix} c_0' & c_1' & c_2' & \cdots & c_{N-1}' & c_N' & c_{N+1}' & \cdots & c_{M-1}' & c_M' & c_{M-1}' & \cdots & c_1' \\ c_1' & c_0' & c_1' & \cdots & c_{N-2}' & c_{N-1}' & c_N' & \cdots & c_{M-2}' & c_{M-1}' & c_M' & \cdots & c_2' \\ c_2' & c_1' & c_0' & \cdots & c_{N-3}' & c_{N-2}' & c_{N-1}' & \cdots & c_{M-3}' & c_{M-2}' & c_{M-1}' & \cdots & c_3' \\ \vdots \\ c_1' & c_2' & c_3' & \cdots & c_N' & c_{N+1}' & c_{N+2}' & \cdots & c_M' & c_{M-1}' & c_{M-2}' & \cdots & c_0' \end{bmatrix}$$

where $c_m' = c_{kj}'$ and $|k-j| = m$, and form a new vector $\hat{a}_k'$, of order $2M$, by augmenting $\hat{a}_k$

$$a_k'^T = [\hat{a}_{k1} \quad \hat{a}_{k2} \quad \cdots \quad \hat{a}_{kN-1} \quad 0 \quad 0 \quad \cdots \quad 0]$$

where $2M$ is a highly composite number, in general a power of 2. The matrix C'' is a circulant matrix, and thus the operation $C''\hat{a}_k'$, a circular convolution, can be done using FFT. We note that the first N elements of $C''\hat{a}_k$ are equal to the elements of $C'\hat{a}_k$. When $2M$ is sufficiently large, the application of matrix C'' to a vector $\hat{a}_k'$ can be seen as a bandlimiting operation of frequency f_0. Since the evaluation of h_i in (34) can also be done using FFT algorithm of order $2M$ we have an equation similar to (22) in the discrete case also

$$\hat{a}_{k+1} = D_N\left[\frac{1}{A}h_i + \frac{A-1}{A}B_{f_0}\hat{a}_k\right] \tag{35}$$

in which the operator $D_N[\cdot]$ just retains the first N samples of the sequence in the bracket. The interpretation of the successive steps in the approximation is just as for the continuous case. The computer implementation of (35) is very simple, since it can be written as a DO loop on k and use the FFT algorithm to go back and forth from the time to the frequency domain.

A similar iterative design procedure can be formulated for a general frequency weight $|W(f)|^2$. For a frequency weight $|W(f)|^2$ bounded by S, which vanishes for $|f| > f_N$, we obtain an iterative relation

$$\hat{a}_{k+1} = D_N\left[\frac{1}{S}b_i + B_w\hat{a}_k\right] \tag{36}$$

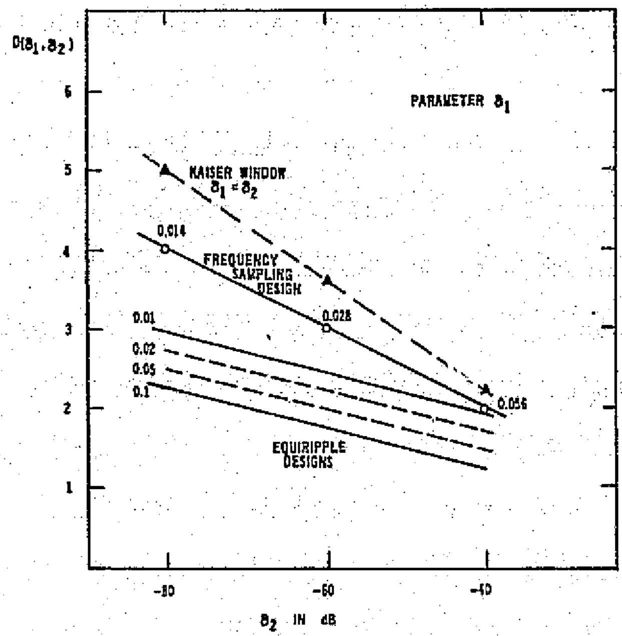
where B_w is a frequency weighting and bandlimiting operator where

$$B_wG(f) = \begin{cases} \dfrac{S - |W(f)|^2}{S}G(f), & |f| \leq f_N \\ 0, & \text{otherwise.} \end{cases}$$

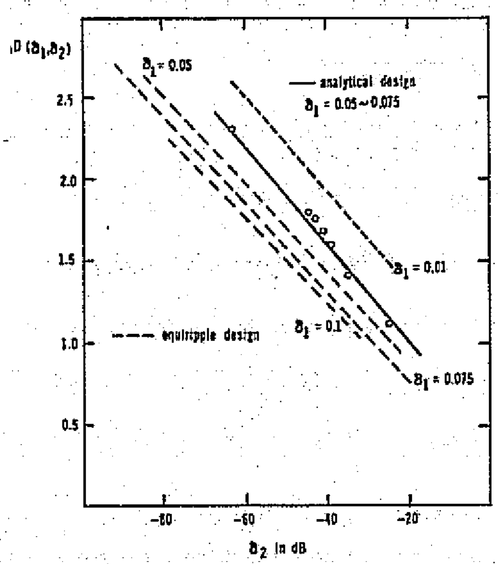
The use of our results from a practical viewpoint in the design of FIR filters is illustrated in the two examples that follow.

Example 1: FIR Low-Pass Filter Design

This is a canonical example for filter designers and its inclusion here is principally to illustrate that old results can be obtained by new methods and to point out some limitations of weighted least-square design. We consider again the ideal filter $H_i(f)$ of (23) and the frequency weight $|W(f)|^2$ of (27), with $f_0 \geq f_c$. The effects of the parameters A and f_0 are as in the case of the design of a low-pass FIR continuous filter.



(a)



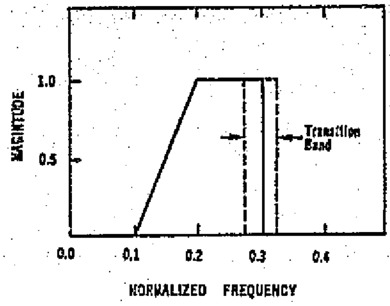
(b)

Fig. 4. Comparison of design techniques. (a) Other design techniques. (b) Analytical design technique.

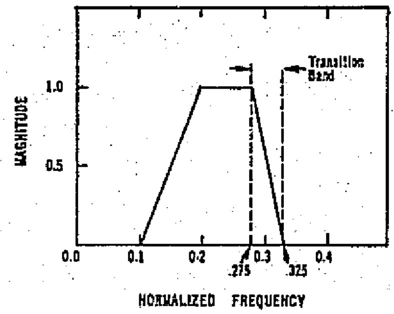
Here the filter was determined by inversion of the corresponding Toeplitz matrix C, an extremely fast computation. To compare with the frequency sampling technique of Rabiner, Gold, and McGonegal [19], and minimax technique of Herrmann [20], in Fig. 4, we show the normalized width of the transition band [21]

$$D(\delta_1,\delta_2) = NT(F_H - F_L) \tag{37}$$

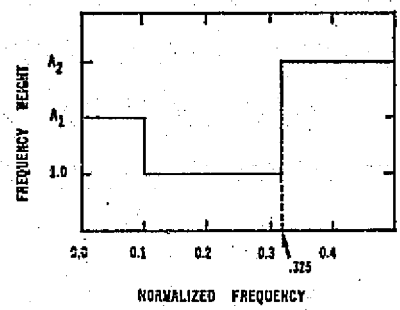
where T is the sampling period, and thus NT is the duration of the impulse response.[8] (Refer to Fig. 1 for the definition of parameters.) Since we use an integral measure of approx-



(a)



(b)



(c)

Fig. 5. Weighted least-square design of FIR digital filter. (a) Ideal frequency model. (b) Modified ideal frequency model for weighted least-square design. (c) Frequency weight used in weighted least-square design.

imation we do not have a precise control of δ_1 and δ_2 or D. We thus vary the control parameters f_c, f_0, and A and measure δ_1, δ_2 and D on the filters obtained. We have least control over δ_1 but in terms of δ_2 and D we see that the results are comparable to those of the minimax techniques.[9] A more systematic approach to the design using weighted least-square is outlined in the next example.

Example 2

We now consider the design of a filter shown in Fig. 5(a). The specifications are:

passband: $0.1 \le |f| \le 0.275$ within a magnitude error of 0.02;

transition band: $0.275 < |f| \le 0.325$;

stopbands: $\left.\begin{cases} 1.\ |f| \le 0.1 \\ 2.\ 0.325 < |f| < 0.5 \end{cases}\right\} \le -50$ dB.

[8] Fig. 4(a) is reprinted from [21]. A similar figure in [20] is in error for filters designed using Kaiser windows. The authors acknowledge one of the reviewers for pointing out this error.

[9] From Fig. 4(a) we note that the filter designed by the techniques of this paper is slightly inferior to the minimax filter (about 15 percent larger D for the same δ_2).

TABLE I
WEIGHTED LEAST-SQUARE DESIGN OF FILTER OF FIG. 5

A_1	A_2	minimum attenuation in stopband 1 (dB)	minimum attenuation in stopband 2 (dB)	magnitude error in passband
1	1	-43.63	-37.45	0.015
1000	1000	-53.35	-54.06	0.023
100	100	-51.8	-46.16	0.0125
100	1000	-50.74	-53.24	0.0177

The number of samples needed is determined by the transition band specifications. As a rule of thumb we use the rejection properties of $\phi_0(t)$ and the transition bandwidth to obtain an estimate of N. For 50-dB stopband rejection the time-bandwidth product should exceed 2.2π. Using $f_t = 0.05$ and $\pi f_t N = C$ we conclude that $N > 44$. We chose $N = 60$ to also meet Kaiser's criteria for the same design using the Kaiser window. In the weighted least-square design we used the ideal model of Fig. 5(b) and the weight shown in Fig. 5(c). Note that we include the transition band in the model. The design took 4 steps with the results shown in Table I.

To compare the results to a design using the Kaiser window we use the criteria set by Kaiser [3] for the window

$$w(t) = \begin{cases} \dfrac{I_0[\alpha\sqrt{\tau^2 - t^2}]}{I_0(\alpha\tau)}, & |t| \le \tau \\ 0, & |t| > \tau. \end{cases}$$

In order to meet the transition band and stopband specifications we used $N = 60$ and $\alpha = 4.5512$.

The filter design using the Kaiser window does meet the transition band and stopband 2 specification but not the passband or stopband 1 specifications. The problem is that the desired passband response is smeared into stopband 1 by the Kaiser window with no possibility of control. Fig. 6(a) and (b) illustrate the differences in the results obtained by the two design techniques. The design using the Kaiser window, Fig. 6(a), eventually exceeds stopband 1 specifications, but the transition into the stopband is slow with a response of -33 dB at $f = 0.1$. Weighted least square, Fig. 6(b), has more flexibility and better control of the filter behavior in the neighborhood of $f = 0.1$. Note that in the flat portion of the passband response, the use of the Kaiser window leads to extremely small error.

These two examples illustrate for the reader strictly interested in FIR filter design the possibilities and limitations of weighted least-square design. Steps to follow in a design procedure are as follows.

1) Choose N to exceed the time-bandwidth product requirement set by the transition band and by the stopband rejection properties of $\phi_0(t)$.

2) Do a least-square design ($A = 1$) and check the frequency responses in the passbands and stopbands.

3) Do a weighted least-square design with large weights in the stopbands to check the rejection actually achievable in the stopbands.

4) Decrease and/or adjust the stopband weights to improve the passband response if the stopbands specifications are exceeded.

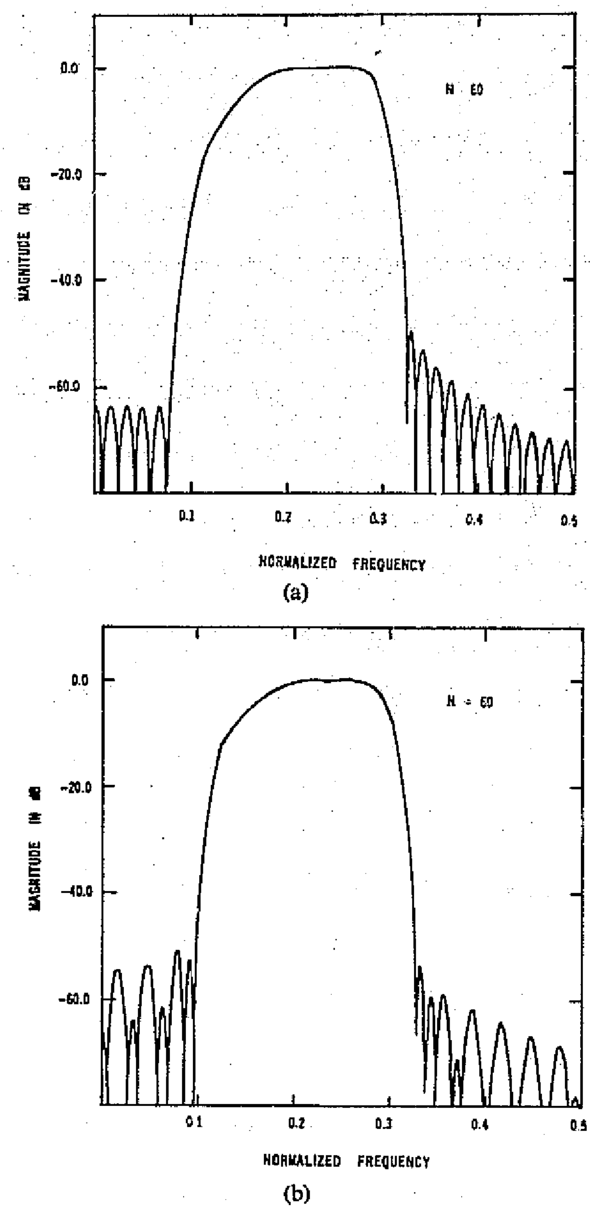


Fig. 6. Frequency response of filters designed by (a) using Kaiser window, and (b) using weighted least-square design technique.

For the actual weighted least-square design, the matrix inversion using properties of Toeplitz matrices is extremely fast. The iterative technique using FFT is extremely convenient to use to trim the response to meet specifications. For a fixed error weight, one then observes at each step the increase in stopband rejection and the iterative process may be stopped when the specifications are met.

Nonuniformly Spaced Filters

For some applications, we are interested in the design of FIR discrete filters and windows where the discrete time instants $\{t_0, t_1, \cdots, t_{N-1}\}$, on which the filter impulse response is defined, are nonuniformly spaced [22]. The eigenvalue–eigenvector approach and matrix inversion approach can be extended to this problem without any modification. However, the matrix C is no longer a Toeplitz matrix. To explore how traditional techniques would work, a set of time

instants was chosen at random. Conventional windows sampled at these time instants exhibit an erratic frequency behavior. A window designed using a weighted least-square approach for the same problem leads to usable results, with significant side lobe attenuation.

Another interesting problem is the case when we are free to choose the time instants $\{t_0, t_1, \cdots, t_{N-1}\}$ to improve the frequency response. Numerical optimization techniques such as the Fletcher–Powell search procedure car be applied to find optimal a_k's and t_k's. In an example of a low-pass filter, a significant increase (> 5 dB) in stopband attenuation was obtained for a filter with 8 nonuniformly spaced samples as compared to uniformly spaced samples.

VI. Design of Two-Dimensional Finite-Duration Filters

Two-dimensional finite-duration filters, continuous and discrete, have a wide application in image processing; for example, geometric correction and interpolation, and image filtering or restoration. The constraint of finite duration is quite important in two-dimensional filters since the data being processed itself has a limited duration. Much of our previous work can be extended to two dimensions. We have now a weighted integral square to minimize

$$I = \iint_{-\infty}^{\infty} \{w(x,y)**[h_i(x,y) - h_a(x,y)]\}^2 \, dx \, dy \tag{38}$$

$$= \iint_{-\infty}^{\infty} |W(f_x,f_y)|^2 |H_i(f_x,f_y) - H_a(f_x,f_y)|^2 \, df_x \, df_y. \tag{39}$$

We require $h_a(x,y)$ to vanish outside the region D.

For continuous filters and windows an integral equation has to be solved for the optimal $h_0(x,y)$

$$Q(x,y) = \iint_D P(x - \xi, y - \eta) h_0(\xi,\eta) \, d\xi \, d\eta, \qquad (x,y) \in D \tag{40}$$

where

$$Q(x,y) = \iint_{-\infty}^{\infty} P(x - \xi, y - \eta) h_i(\xi,\eta) \, d\xi \, d\eta \tag{41}$$

and

$$P(\alpha,\beta) = \iint_{-\infty}^{\infty} w(x,y) w(x - \alpha, y - \beta) \, dx \, dy. \tag{42}$$

Assume that $H_i(f_x,f_y)$ vanishes outside of a region B_0 and choose a piecewise constant weight $|W(f_x,f_y)|^2$ such that

$$|W(f_x,f_y)|^2 = \begin{cases} 1, & (f_x,f_y) \in B_1, \quad B_1 \supset B_0 \\ A, & \text{otherwise} \end{cases}$$

then the integral equation (40) becomes

$$Q(x,y) = A h_0(x,y) - (A - 1) \iint_D K_{B_1}(x - \alpha, y - \beta) h_0(\alpha,\beta) \, d\alpha \, d\beta, \qquad (x,y) \in D \tag{43}$$

where

$$K_{B_1}(\alpha,\beta) = \iint_{B_1} e^{j2\pi(\alpha f_x + \beta f_y)} \, df_x \, df_y. \tag{44}$$

Applying the Neumann series approach, we can again derive a recursive relation for successive approximations. The $(k + 1)$th approximation of $h_0(x,y)$ is given by

$$\hat{h}_{k+1}(x,y) = \frac{1}{A} Q(x,y) + \frac{A - 1}{A} \iint_D K_{B_1}(x - \alpha, y - \beta) \hat{h}_k(\alpha,\beta) \, d\alpha \, d\beta. \tag{45}$$

Special Cases

1) *Separable Filters:* When $h_i(x,y)$ is separable, i.e., $h_i(x,y) = h_{ix}(x) h_{iy}(y)$ then the problem becomes a simple extension of a one-dimensional case if the frequency weight is also separable.

2) *Circularly Symmetric Case: Isotropic Filters:* If the area D is a circle with a radius r_0 centered at the origin, $h_i(x,y)$ is a function of only $r = \sqrt{x^2 + y^2}$, and the weight, $P_R(r)$, has circular symmetry then the optimal circular symmetric window or filter $h_0(r)$, is the solution of the integral equation

$$Q_R(r) = \int_0^{r_0} \rho P_R(\rho) \int_0^{2\pi} h_0(\sqrt{r^2 + \rho^2 - 2r\rho \cos \theta}) \, d\theta \, d\rho \tag{46}$$

Example: Design of a circular symmetric low-pass filter: Let our model $H_i(f_x,f_y)$ be

$$H_i(f_x,f_y) = \begin{cases} 1, & \text{for } \sqrt{f_x^2 + f_y^2} \le \rho_0 \\ 0, & \text{otherwise.} \end{cases}$$

Then all procedures are similar to the case of one-dimensional low-pass filter design with a two-dimensional eigenvalue–eigenfunction problem to solve

$$\iint_D K_B(x - \alpha, y - \beta) \psi_k(\alpha,\beta) \, d\alpha \, d\beta = \lambda_k \psi_k(x,y) \tag{47}$$

where B is a circle with radius ρ_1 centered at the origin. The eigenfunctions and eigenvalues of (47) are discussed by Slepian [23] and are known as generalized prolate spheroidal functions. The Neumann series approach can be applied to the solution of (45) for an isotropic case as well. Using a numerical Hankel transform program, the Neumann series was used to increase the attenuation in the stopband of an isotropic low-pass filter. The results

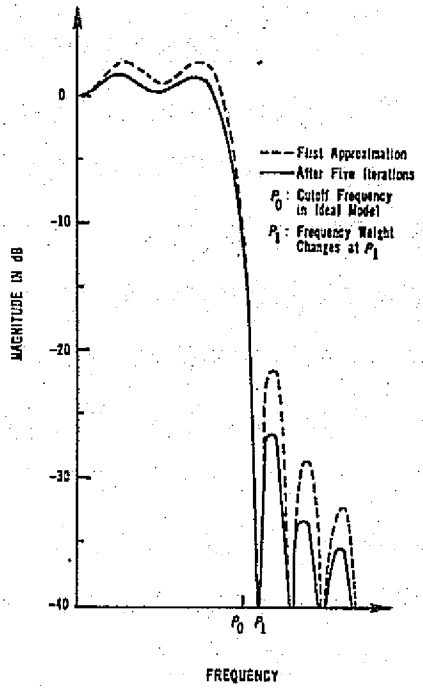


Fig. 7. Example of two-dimensional isotropic filter design.

of 5 iterations with $A = 3$ are shown in Fig. 7. We obtain 5 dB of additional attenuation at the expense of a very slight increase in the transition band.

Two-dimensional discrete filters can also be designed using the techniques of this paper. Most such extensions appear conceptually straightforward, but there are a number of cases of theoretical or practical interest to be examined such as different sampling grid and constraints on duration.

VII. Conclusions

In this paper we cast the problem of designing filters of finite duration as the problem of approximating desired filter characteristics in a weighted least-square sense. This approach leads to new theoretical results and to mathematically tractable practical design techniques for conventional and nonconventional filters. For continuous filters, the solution of the optimum weighted least-square filter in terms of eigenvalues and eigenfunctions made apparent a natural conceptual link between the properties of optimum windows and the properties of optimum low-pass filters. Continuous filters can also be found ite1 ıtively using the Neumann series without knowledge of the eigenfunctions.

In the discrete case, the direct solution of the optimum weighted least-square filter is quite straight forward using matrix inversion if the number of samples is from small to moderate. For a large number of samples and in two dimensions, successive approximations using the discrete equivalent of the Neumann series is an approach both very simple and intuitively pleasing.

Flexibility in design can be achieved by adapting the error weighting function, in an interactive mode, to match the design objectives. For traditional one-dimensional FIR filter design the weighted least-square approach should be rated as a simple and flexible design technique, but without the degree of error control of the minimax approach.

More generally, the techniques presented here seem most useful for nonconventional and spatial filters for which the extension of usual FIR design techniques is not possible or is too restrictive. In particular, further experience of the authors with the methods presented in this paper show them to be quite attractive in image processing where more conventional approaches fail or become computationally cumbersome.

Appendix

Orthogonality Condition

We derive an orthogonality condition for the minimization problem of (4) and rewrite for an arbitrary $h_a(t)$ and an optimum $h_0(t)$,

$$I = \int_{-\infty}^{\infty} \{w(t)*[h_i(t) - h_0(t) + h_0(t) - h_a(t)]\}^2 \, dt. \tag{A-1}$$

After expanding the square it becomes clear that the necessary and sufficient condition for $h_0(t)$ to be an optimal solution is that

$$\int_{-\infty}^{\infty} \{w(t)*[h_i(t) - h_0(t)]\}\{w(t)*[h_0(t) - h_a(t)]\} \, dt = 0 \tag{A-2}$$

for any duration limited function $h_a(t)$. Since $h_a(t)$ is an arbitrary duration limited function, so is $h_b(t) = h_0(t) - h_a(t)$. If (A-2) is to be satisfied for any duration limited functions, it should be satisfied for the impulse function $h_b(t) = \delta(t - \alpha)$ for any α, $|\alpha| \leq T/2$. Thus we obtain

$$\int_{-\infty}^{\infty} w(t - \alpha)\{w(t)*[h_i(t) - h_0(t)]\} \, dt = 0, \qquad |\alpha| \leq T/2. \tag{A-3}$$

Let us define

$$R(\alpha - \beta) \triangleq \int_{-\infty}^{\infty} w(t - \alpha)w(t - \beta) \, dt \tag{A-4}$$

then (A-3) becomes

$$\int_{-\infty}^{\infty} R(t - \beta)h_i(\beta) \, d\beta = \int_{-T/2}^{T/2} R(t - \beta)h_0(\beta) \, d\beta. \tag{A-5}$$

The left-hand side is known for all t, and we call it $Q(t)$, then we have an integral equation to solve for $h_0(t)$,

$$Q(t) = \int_{-T/2}^{T/2} R(t - \alpha)h_0(\alpha) \, d\alpha, \qquad |t| \leq T/2. \tag{A-6}$$

If $S(f)$ is the Fourier transform of $R(t)$, it can easily be seen that

$$S(f) = |W(f)|^2. \tag{A-7}$$

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CHAPTER 7

SUMMARY

Robert N. Colwell

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Robert N. Colwell

7.0 Water has continued to be the primary resource receiving attention under our integrated, multicampus study. During the period covered by this progress report, our research efforts have continued to be concentrated along the lines set forth, at NASA's request, in our statement of 30 September, 1973. Thus we have continued to concern ourselves primarily with the usefulness of remote sensing in relation to two aspects of California's water-related problems: (1) those pertaining to water supply in northern California, (dealt with primarily by personnel of the Davis and Berkeley campuses as reported upon in Chapters 2a and 2b, respectively); and (2)those pertaining to water demand in central and southern California (dealt with primarily by personnel of the Santa Barbara and Riverside campuses, as reported upon in Chapters 3 and 4, respectively).

It will be evident from a reading of Chapter 5 that our Social Sciences Group also contributes greatly to the integration of our multicampus study as they seek to acquire insights into the very complicated web of factors impinging on the management of California's water resources. Their primary objective in this work is to learn how new sources of water-related information can be accomodated, by whom, and for what purpose. Their work has done much to document, in highly specific terms, the important fact that resource management decisions do not take place in a technological, economic, political and social vacuum but in a real-life, rapidly changing environment.

7.1.0 The following facts are described in Chapter 1 of this progress report:

7.1.1 It is important, especially in an area such as the state of California wherein the economy depends so heavily on indigenous water resources, that these resources be adequately renewed each year.

7.1.2 Although in California the primary renewal time (period of precipitation) normally is from November to March there are predictions that California's rainfall during that period in the 1975-76 season will be only one third as great as in even the driest previously recorded year, i.e. three times drier than during any year of the past century.

7.1.3 The impact on California's economy resulting from such a dry season is potentially very great since it is generally recognized that water is the most valuable of all of California's resources.

7.1.4 The impact during any single year of drought is restricted largely to annual crops of the type that are grown without irrigation (e.g. most of the wheat, oats, and barley crops as well as the wildland forage crops that grow in California's vast foothills areas) and to the livestock industry of the state since such crops are the primary source of feed for California-grown livestock.

7.1.5 Should the present dry season be followed by an equally dry one in the winter of 1976-1977, however, the damage probably would be an order of magnitude greater because this would lead almost to complete depletion of the reservoirs and subsurface water storage zones on which California's vast irrigated agricultural industry depends (and which also satisfies California's industrial and domestic demands).

7.1.6 In view of these considerations, it is all the more appropriate and timely that the research efforts of our integrated study have been concentrated so heavily on the supply and demand aspects of California's water resources and upon the economic, social, political and cultural phenomena of the state that are so closely related to those particular resources.

7.2.0 As described in Chapter 2, during the present reporting period work performed by Algazi et al of the Davis campus has been concentrated on water supply problems and, more specifically, on the application of remote sensing to the inventory and management of California's water resources, using the California Water Project as the primary focus of those studies.

7.2.1 Among the specific activities of the Algazi group during the period covered by this report are the following:

a. Sensitivity analyses have been made of certain watershed models that are amenable to remote sensing inputs. These analyses have sought to determine (a) the effect which changes in dynamic inputs of model parameter information are likely to have on runoff predictions, and (b) the optimum times for acquiring such inputs. The group has found that, for the forecasting of monthly runoff, there are two factors which are the most pertinent. These are (1) precipitation at all times of the year and (2) evapotranspiration in the Spring of the year. Since snow constitutes a very significant part of California's total precipitation, the forecast and monitoring

of snowfall and snowmelt can be of especial importance. An appendix to the Algazi chapter gives many details with respect to this aspect of his study and it is anticipated that definitive, quantitative conclusions with respect to the usefulness of remote sensing in the monitoring of snowfall and snowmelt can be included in the annual report that is due in May, 1976.

b. A substantial study has been made to determine which parameters derivable from satellite remote sensing data are most pertinent with respect to California's hydrologic models. This work has thus far been concentrated on parameters which are most pertinent to snow hydrology, and especially to snow ablation. The qualities that appear to be most important in the modeling of basinwide snowmelt are the temperature, albedo, topography, areal extent of snow, spatial distribution of precipitation, and snowcover. Since many of these factors can change rapidly with time, the Algazi group has undertaken to incorporate satellite data into a physically based, distributed model of snowmelt in order to improve runoff predictions. Data used have included NOAA-3 and -4 satellite data. Because of the highly distorted view of the earth provided by such satellites, geometric correction of that data became mandatory. Although unusually great problems were encountered in attempting to convert numerical NOAA satellite values or counts into earth surface temperatures, the Algazi group finally succeeded in solving this problem, as documented in Chapter 2a.

c. An attempt was made to measure snowpack albedo, since this factor obviously has a close relation to snowmelt. Preliminary results indicate that of the remote sensing data sources currently available, LANDSAT band 7 data will provide the best indicator of albedo at the level of resolution desired. (NOAA satellite thermal infrared data would be preferable except that the resolution of such data is only 0.9 km and thus is not sufficiently detailed). Investigations also are underway by the Algazi group to study the changes with time in the albedo of selected snowpack areas. Modifications in albedo values attributable to relief and vegetation cover, area-by-area, also are being studied.

d. Correlations between estimates of areal extent of snow, as obtained from LANDSAT data, and those obtained from NOAA satellite (visible band) data also are being established by the Algazi group.

e. Techniques for the processing of digital remote sensing data have been investigated by the Algazi group during the present reporting period, but only with moderate success, thus far. Specifically,

because of the high correlation both spectrally and spatially in LANDSAT-type data the Algazi group is attempting to achieve various combinations of such data. Such a capability could also constitute an important first step leading to the combination of LANDSAT data with data acquired from NOAA satellites and from certain other remote sensing systems. Some geometric correction algorithms have been developed. Also, in an effort to derive sub-pixel information the Algazi group has made progress in interpolating between pixels. Finally, in an effort to remove the highly troublesome noise in NOAA thermal infrared data, the Algazi group has derived a means, analagous to the one which they previously developed for use with LANDSAT-type data, for removing noise from the NOAA data.

7.2.2 Paralleling, and closely integrated with the work of the Algazi group has been that of the Remote Sensing Research Program on the Berkeley campus, as summarized below:

7.2.2.1 Snow Quantification Technique Development

a. A different means of measuring areal extent of snow has been tested by this group than is tradiationally used. They make this determination by using a two stage statistical estimation procedure that allows the final estimate to be interpreted for its accuracy. Various factors which affect the apparent presence of snow, such as vegetation type, elevation, and aspect are accounted for in this estimation procedure to give the correct estimate. The results of the areal extent of snow estimation are then used, in part, to generate the second key parameter, snow water content.

b. Snow water content is estimated by integrating estimates of areal extent of snow, as described above, with ground measurements collected on several snow courses used by the California Department of Water Resources. The final snow water content estimate is based on the statistically derived correlation between the areal extent of snow information and the ground data.

c. Analyses of the relative cost effectiveness of the procedures just described have shown that such procedures are significantly more cost-effective than those currently being used. Furthermore, the designs used to develop the manual interpretation approach can be used in the future to develop an integrated approach to computr~-aided analysis of the snowpack parameter.

d. Once the computer-aided estimation systems have been developed, the digital nature of LANDSAT data as well as the inherent consistency and speed of electronic analysis can be used to full advantage in providing accurate and timely snowpack parameter estimations for inclusion in water runoff prediction equations. The possibility exists for manual automatic analysis where the interpreter may analyze a computer generated enhancement, thus making optimal use of the complementary capabilities of the humans and the computers.

e. In many cases the method just described for estimating areal extent of snow can already be considered operational. However, some additional research is needed to present to the potential user a choice of the level of sophistication and accuracy that he needs or can afford.

f. The Berkeley method not only corrects the interpreter's snow areal extent classification to photo/ground values based on testing results, but also minimizes variations in final classification results between interpreters. Thus a consistent result can be expected even though areal extent of snow estimation is performed on different areas by different interpreters.

g. Snow water content estimation based on remote sensing techniques shows promise of providing more accurate, less costly and more timely estimates of water runoff than have heretofore been possible. Currently the California Cooperative Snow Surveys, a state agency involved in water supply forecasting, is cooperating in this research. It is anticipated that the resulting procedures will also be tested with the Federal-State River Forecasting Center's water yield model via a coordinated effort with the U.C. Davis Algazi group. Beneficiaries of this information would include users of snowmelt runoff water, such as farmers, ranchers, industrialists and homeowners. Improved knowledge regarding the future availability of water for these groups would statistically tend to reduce monetary losses incurred by their often erroneous assumptions that either more or less water would be available.

h. Briefly stated, the LANDSAT-aided snow water content estimation system developed by the Berkeley group involves the use of a stratified double sample. Its objective is to combine snow water content information for the whole watershed, (as obtained inexpensively from LANDSAT data), with that gained from a much smaller and more expensive sample of ground-based measurements at snow courses.

Details of the procedure are as described in section 2a.2.2 of this report. Results to date indicate a correlation coefficient of .8 to .85 between LANDSAT snow water content index data on a sample unit basis and corresponding ground snow water content measurements. Two-fold improvements in the cost of precision of estimating basin-wide snow water content seem probable using LANDSAT-aided versus conventional snow course measurement systems.

i. The findings are further enhanced by the fact that snow water runoff is one of the major sources of water supply within the California Water Plan, as well as in many other parts of the world. Improved methods of identifying, monitoring, mapping, and modeling our snow water resources at this time can lead to improved methods of predicting and managing this resource in the future.

7.2.2.2 Estimation of the Water Content of Snow.

a. The primary objective of the RSRP Snow Water Content research is to determine if LANDSAT data and a small calibrating sample of snow course measurement data can be readily integrated into operational snow quantity estimation schemes. The goal of this integration would be to provide less costly, more accurate, and potentially more frequent estimates of watershed snow water content than available through current forecasting procedures.

b. A second objective of this study is to determine if this remote sensing-aided snow quantification approach will yield more accurate, less costly, and <u>more timely</u> (i.e. quicker) estimates of water runoff.

c. The results obtained to date indicate substantial potential cost and/or precision advantage to be gained by use of conventional ground measurement snow course data integrated in a double sampling framework with LANDSAT-derived information.

d. It is expected that further improvements in the precision of watershed-wide snow water content estimates can be obtained by optimizing image sample unit size and utilizing more rules decision, (whether manual or computer-mediated) that are specific for the snow accumulation/snow melt environment.

e. One biproduct of the LANDSAT-derived image sample unit data is an in-place mapping of snow water content with respect to known melting environments and stream channels. Such time- and place-specific snow melt records could be used to aid in the selection of new snow course sites or in the placement of automatic snow sensors. Snow pack and relative stream channel position data could also be used in refined models of runoff timing.

f. Human and automatic analysis of daily environmental (meteorological) satellite data, when correlated with less frequent LANDSAT and ground data, offers the possibility of extremely frequent watershed snow water content updating.

g. Hydrologic models of the future will conceivably integrate remote sensing and meteorological data with automatic ground-based snow sensing equipment. Real-time information eventually could be generated for entire watershed or subbasins, depending on the need to assess the overall impact of a major storm or of a minor subdivision.

7.2.2.3 Comparative Cost-Effective Analyses of Procedures for Estimating Snow Water Content.

a. The side-by-side comparison by RSRP personnel of the operational and LANDSAT-aided snow water content estimation systems was facilitated by a blending of statistical and economic theory. Multistage sampling enables an investigator to calibrate a large number of low-cost orbital observations with a small number of ground-based observations. Optimal sample sizes were derived during the present reporting period using a stratified double sampling scheme.

b. Design and evaluation of a LANDSAT-aided approach to snow water content estimation required a thorough examination of the currently operational system. The California Cooperative Snow Survey (CCSS) program, the principal source of water supply forecasts in California, was examined both qualitatively and quantitatively.

c. Use of the allowable error (AE) formulation described in Chapter 2b permitted RSRP personnel to make a direct cost-capability comparison of the two snow water content estimation systems. For the LANDSAT-based sample sizes, AE's were calculated for monthly direct cost budgets of $1,000, $3,000, $4,200, $5,000 and $7,000 at confidence intervals ranging from 80% to 99%. For the CCSS system of snow water content estimation,

AE's were calculated at four confidence levels on a monthly direct cost budget of $4,200. Results for the 95 percent confidence level were derived. They appear in Figures 2b-2 and 2b-3.

d. At the $4,200 budget level, the LANDSAT-aided snow water content estimation method produced results approximately 1.8 times more precise than the existing system.

e. In general, the LANDSAT-aided system yielded relatively precise estimates of total watershed snow water content. For a $4,200 monthly budget, this approach estimated true basin snow water content to within $\pm$ 3.6% ninety-five times out of a hundred.

f. The precision of basin snow water content estimates could be improved still further by using techniques that increase the correlation of orbital to ground snow water content estimates. Smaller image sample units, more environment - specific snow class interpretations, and automatic processing of satellite digital data are some of the more promising of these techniques.

7.2.2.4 Remote Sensing-Aided System for Estimating Evapotranspiration

a. In view of the overriding importance of evapotranspiration to accurate basin water yield estimation and to other water consumptive use determinations, any cost-effective, precise evapotranspiration estimation system would be of significant utility to a water manager.

b. Remote sensing techniques may provide the key to such a system's data requirements. Its timely, spatial, and relatively inexpensive nature when combined with other conventional meteorological data can potentially give rise to accurate, location-specific estimates of evapotranspiration.

c. Current water yield estimation procedures such as the California River Forecasting Center model can incorporate evapotranspiration estimates. It is therefore important to develop a remote sensing-aided methodology for the accurate and efficient estimation of watershed evapotranspiration.

d. The remote sensing-aided system developed by RSRP to estimate evapotranspiration is designed to give timely, relatively accurate, cost-effective evapotranspiration estimates on a watershed or sub-watershed basis. The system employs a basic two stage, two phase sample of three information resolution levels to estimate this important water yield-water use related quantity.

e. A necessary documentation of assumptions, structure, and limitations of current evapotranspiration models has been performed. Based on this analysis recommendations have been made concerning the applicability of these models to evapotranspiration estimation at various information levels corresponding to given stages and phases of the sampling design.

f. Based on the foregoing design, documentation, and feasibility analysis, work is now proceeding to implement the remote sensing-aided system. Effort will be focused on refining the sample design, developing in detail the supporting data flow mechanism, gathering additional data, and modifying the evapotranspiration models for their respective information levels.

g. These modifications will be based on the performance of the proposed ET models at their information resolution level. Model performance will be evaluated relative to observed evaporation data and point-estimations of actual evapotranspiration data. These point estimations of actual ET data are based on energy-balance utilizing the measured values of the input variables on the ground.

h. The input data for models requiring spatial information will be provided by a computer-aided databank. The RSRP software for this databank, known as MAPIT, will allow a geometrically coincident combination of LANDSAT-related data, environmental satellite data, ground meteorological station data, ground sample unit information gathered by RSRP and others, and topographic data.

i. Input data sets and evapotranspiration estimate output will be coordinated with concurrent sensitivity analyses of State of California water yield models performed jointly by the Davis and Berkeley NASA Grant groups.

j. The final product will be a documentation of any improvements in accuracy, timeliness, and cost considerations for the determination of water yield attributable to the remote sensing-aided evapotranspiration estimation system. Results will be specific to the state-of-the-art hydrologic models under examination.

7.2.2.5 Remote Sensing-Aided System for Estima'ing Impervious Surface Area

a. The water impervious surface area (ISA) is an important parameter in estimating water runoff. ISA's may be described as those areas which exhibit almost instantaneous runoff into adjacent areas and stream channels when precipitation occurs.

b. The method employed in this phase of the RSRP study has been designed to accurately and cost-effectively estimate the hard, meadow and soft ISA's of a representative area in such a manner so to be statistically applicable in water-yield estimation models.

c. This investigation has developed a multistage sampling technique for quickly utilizing available LANDSAT data to estimate ISA in a manner compatible to use in other water outflow studies. Based on the methods described in Chapter 2h of this report, an ISA estimation for an area of 536 km^2 may be done within a period of 10-12 work hours.

d. ISA estimations to be used in a PSA study may require somewhat longer, but still remain within a period of 24-26 work hours.

e. Neither of these limitations includes acquisition of ground truth data or time spent locating and processing imagery, each of which consumes a greater portion of time than the actual analysis. In addition, each will vary considerably with one's "on-hand" available resources.

7.3.0 During the current reporting period, the Geography Remote Sensing Unit, (GRSU) on the Santa Barbara Campus has been concentrating its research effort on the following water demand related topics:

a. An analytical and empirical analysis of those variables which have a significant effect on a remote sensing agricultural water demand prediction procedure;

b. The development and/or refinement of manual and semi-automatic remote sensing techniques to extract data relevant to these variables;

c. Comparison of remote sensing techniques for acquiring information on specific water demand related parameters with conventional methods to draw conclusions regarding cost-effectiveness;

d. An experimental water demand prediction for Kern County Water Agency hydrologic model nodes in the Wheeler Ridge-Maricopa Water Storage District to assess the semi-operational utility of proposed remote sensing procedures; and

e. Initiation of research to determine whether water demand prediction procedures created for a semi-arid environment can be effectively applied in more temperate climatic regions, requiring slightly different water demand parameters.

7.3.1 GRSU points out that a recent study dealing with the Total Earth Resource System for the Shuttle Era identified two high priority remote sensing missions as being:

a. survey and monitor U.S. cropland to calculate short-and-long run demand for irrigation water;

b. survey and inventory the volume and distribution of surface and groundwater to assess available supplies for urban and agricultural consumption.

7.3.2 In order to develop a remote sensing irrigation water demand prediction methodology a representative region was located which possessed a sufficient range of environmental parameters, both physical and cultural, to accurately gauge the success of the proposed techniques. Kern County, California, was selected because:

a. It is one of the major agricultural counties in the United States with an estimated value of direct farm marketings in 1974 of over $700,000,000;

b. This production is primarily dependent on the irrigation of about 356,000 harvested hectares (990,000 acres); and

c. To support this level of agricultural production, Kern County will consume over 660,000 acre-feet of California Aqeuduct water alone in 1975, at a mean cost of $20 per acre-foot.

7.3.3 The interface of remote sensing-derived information with the present Kern County groundbasin model should facilitate a near real-time prediction of agricultural water demand, thus enabling the Kern County Water Agency to anticipate:

a. The total amount of water demand (ground and/or imported) on a seasonal basis;

b. The amount of imported water available and/or demanded for groundwater replenishment;

c. Possible water exchanges and rerouting alternatives

7.3.4 During the present reporting period, the GRSU, identifying those input parameters amenable to remote sensing and in turn concentrating on those parameters which carry the most leverage in the water demand prediction, sought to develop remote sensing techniques and methodologies to meet the KCWA models' data requirements. This effort has now progressed to where, in the near future, data derived from remote sensing will be utilized in a dedicated model run and the results compared to a similar run based solely on conventionally derived data.

7.3.5 The GRSU analysis shows that, for each 1% of increased efficiency in the application of irrigation waters resulting from the use of imporved data in the hydrologic model, approximately 12.5 additional sections could be brought into production. An addition of this magnitude would represent a crop value of approximately $6,250,000 per year. In view of such values, some comparative cost analyses between conventional and remote sensing techniques have been documented.

7.3.6 In addition, a substantial research effort is currently being directed by the GRSU at determining the cost-effectiveness of the remote detection of several other parameters i.e., croptype, soil salinity, and perched water. It is hypothesized that in addition to being cost-effective in their own right, several of these remote sensing procedures may also help increase the efficiency of mandatory terrestrial data surveys by creating a more accurate stratification plan for sampling or mapping.

7.3.7 GRSU research on the development of remote sensing techniques for the generation of water demand statistics is leading to a remote sensing/user agency data flow as illustrated in Chapter 3. In such instances, remotely sensed agricultural acreage and its

inherent components (i.e., croptype, fallow, double cropping, etc.) are extracted (classified) primarily from LANDSAT data which has had supervised training sets defined. The irrigation rates from auxillary data are refined through remote sensing (i.e., croptype, pre-irrigation, salinity leaching requirement). These two data sets are then interrogated to yield the output irrigation water demand prediction statistics. These statistics are then used by the user agencies, i.e., KCWA, Water Storage Districts, agribusiness concerns, etc. to optimize the water management decisions discussed earlier.

7.3.8 A short term objective of the GRSU research is the quantification and rank ordering of the individual variables involved in water demand prediction. In addition to crop specific effects, the other variables studied to date include: fallow land, double-cropping, and pre-irrigation. These variables have been selected for study because of their anticipated importance and/or their amenability to study using remote sensing techniques. It is anticipated that water pricing policies and soil type effects will be analyzed during the next reporting period. All of these variables affect either the acreage estimate or the irrigation rates, the two basic inputs of the water demand prediction procedure.

7.3.9 A longer term objective of this research is the development of techniques to accurately predict total irrigation water demand and to determine its source. These techniques are being developed to operate on a nodal scale as required by the KCWA model. At present, the water prediction techniques are being developed using high altitude photography, LANDSAT imagery, and field survey crop maps. However, the project is oriented towards the development of cost-effective techniques using LANDSAT imagery.

The immediate goal of this phase of the study is to quantify the effect of selected variables on the accuracy of nodal water demand predictions and to identify those remote sensing techniques and methodologies which will facilitate the inclusion of these variables in a water demand prediction procedure.

7.3.10 During the present reporting period, GRSU has investigated each variable (i.e. crop type, fallow land, pre-irrigation, and double cropping) individually to quantify the particular effect on the accuracy of its inclusion or exclusion in a water demand prediction procedure. For most variables, the effect on accuracy has been quantified for both of the two basic prediction methods, one using cropland data and the other utilizing crop type data.

7.3.11 Predictions generated from two procedures, one utilizing crop type data on a nodal basis and one using just cropland (i.e. agriculture/nonagriculture) have been compared in order to quantify the increase in accuracy due to the inclusion of crop type data in the water demand prediction. Predictions have been made for each of the 40 nodes in the Wheeler Ridge-Maricopa Water Storage District for the years 1972, 1973, and 1974. It was found that the inclusion of crop-type data significantly increases the district-wide mean nodal water demand prediction accuracies by 6.3% for the three years studied; much larger impacts are possible and have been noted in the Lost Hills District.

7.3.12 In a water demand prediction procedure using cropland data, the inclusion of fallow acreage in the cropland (irrigated) acreage estimates will result in an overestimation of crop acreage, and therefore an overestimation of water demand.

The change in cropland water demand prediction accuracies with and without fallow data have been computed by GRSU for the Wheeler Ridge-Maricopa Water Storage District for the years 1972-1974. The overall increase in water demand prediction accuracy for the three year time period was found to be 7.9%.

7.3.13 GRSU also has investigated the effect of pre-irrigation information on water demand prediction accuracies. (Pre-irrigation is the preliminary application of water to new cropland, primarily to increase the soil moisture to a sufficient level for the first planting). The effect of the inclusion of pre-irrigation data on nodal predictions made with cropland data has been calculated for the Wheeler Ridge-Maricopa District for the years 1973 and 1974. Water demand due to pre-irrigation has been estimated by multiplying the pre-irrigated acreage by an annual Kern County average pre-irrigation rate. The increase in accuracy with the inclusion of pre-irrigation data for these two years was found to be 2.8%.

7.3.14 In still another study the GRSU at Santa Barbara studied the effect of multiple-cropping information on water demand prediction accuracies. (Multiple cropping is the presence in one field of two or more successive crops which complete all or most of their phenological cycle within one year.) The occurrence of multiple cropping in an area effectively increases the cropped acres in an area by a factor of two or more, and thus, significantly increases the water demand of that area. In a water demand prediction procedure it is necessary to include data on multi-cropped areas in order to prevent underestimation of the water demand. The increase in water demand prediction

accuracy due to the inclusion of multiple cropping information in a prediction made with cropland data was found to be 2.8% for 1974. The effect of the inclusion of double-cropping data on nodal predictions made with crop type data also was calculated. The result was a district-wide mean nodal increase in percent accuracy of 3.6%.

7.3.15 Also during the present reporting period the GRSU, in cooperation with KCWA, has completed an indepth analysis of the accuracy and cost-effectiveness of remote sensing techniques for acquiring cropland data. Over 184,000 hectares (456,000 acres), nearly one third of Kern County's agricultural lands, have been inventoried by: 1) terrestrial investigations conducted by cooperating water districts, 2) photo interpretation of high altitude color infrared photography, and 3) image interpretation of LANDSAT multispectral imagery. Analysis of the data generated by these inventories provided the basis for accuracy and cost-effectiveness comparisons. Cropland information collected in connection with this study is required as input to the groundbasin hydrology model of the San Joaquin Valley portion of Kern County.

7.3.16 Before remote sensing techniques could be used to generate meaningful inputs to the water demand model that had previously been devised, it was necessary to determine exactly what types of inputs were likely to be useful. This analysis concluded that the most dynamic element of water movement into and through the Kern County groundwater basin occurs as a result of the application of irrigation water to agricultural lands.

7.3.17 To test the potential of remote sensing for providing cropland information as a model input, research was directed towards a comparison of several methodologies which employed remotely sensed data and conventional ground survey techniques. This research documented both relative and absolute accuracy as well as the cost-effectiveness of inventorying cropland by:

a. Conventional terrestrial methods
b. Color infrared high altitude (1:125,000) photography
c. LANDSAT (1:1,000,000; band 5) imagery

In this study it was found that the high altitude cropland inventory had mean relative and absolute errors of 0.3% and 2.9% respectively. The mean relative error for LANDSAT cropland inventories was found to be less than 1%, while the mean absolute error was 2%. This is significant because even though the scale

has been decreased and resolution degraded when compared to 1:125,000 photography, the LANDSAT technique is capable of achieving a comparable, and in this case study even slightly higher, absolute accuracy, i.e. 98% versus 97%. This is attributed to the multitemporal characteristic of LANDSAT and its ability to provide adequate resolution for many dates throughout a growing season. It was also found in these studies that, the remote sensing cropland inventories are cost-effective. Compared to the $62-66 cost per 4,050 hec for the DWR and Water District cropland inventories, the high altitude and LANDSAT inventories required only 3-5% of this amount, i.e. $1.97 - 2.98 per 4,050 hec. The mean time for the DWR and Water District inventories was 235 hours while the remote sensing inventories required only 12 hours. This represents a 95% reduction in time when croplands are inventoried using high altitude or LANDSAT techniques. Cropland data generated by these techniques is now being regularly input into the KCWA hydrology model. Current research is documenting the utility and cost-effectiveness of remote sensing techniques, based primarily upon LANDSAT imagery, for providing specific crop type information as an additional model input to predict water demand.

7.3.18 In October, 1975, the Kern County Water Agency proposed an arrangement with GRSU whereby a photo interpreter would be hired by KCWA on a part-time basis to provide quarterly cropland acreage statistics for input to the KCWA hydrologic model. This KCWA employee will be trained by GRSU to utilize the LANDSAT cropland inventory technique previously described. Based on problems encountered as the technique is transferred to the agency, a cropland inventory "cookbook" is being prepared as a NASA document for the benefit of other user agencies.

7.3.19 The ability of the GRSU to register and interrogate LANDSAT Computer Compatible Tapes (CCT's) has nearly reached operational status. However, hardware delays have necessitated the use of video (analog) densitometric extraction techniques. When CCT's can be utilized by our image processing system, the improvement in radiometric accuracy should result in improved classification accuracies. GRSU's video image analyzer is currently being integrated into the UCSB Computer System Laboratory's (CSL) Interactive Signal Processing System thereby expanding our image processing capabilities. This digital image processing system will facilitate the use of various automated and semi-automated techniques for data extraction and analysis.

7.3.20 A separate study was conducted by GRSU to determine the feasibility of identifying crops in the San Joaquin Valley from LANDSAT imagery. Although apparently not as accurate as expected, the LANDSAT based classification resulted in more accurate water demand predictions than the conventionally derived field predictions. Of the fields incorrectly classified, the lowest class assigned probability was .914, suggesting the very real possibility that the LANDSAT classification may be more accurate than the field map. The remote sensing crop identification procedure used in this study can be employed by any user having access to simple densitometric equipment and a discriminant analysis classification algorithm. Further research will investigate the usefulness of other algorithms (including the maximum likelihood algorithm of LARSYS) for identifying crops in Kern County. Specific countinuing research topics include the value of per-field versus pixel-by-pixel classification, and signature extensions, both temporally and spatially. The results of this research will have a significant impact upon the findings of our cost-benefit analysis of operational remote sensing programs for crop identification and consequently for water demand estimation.

7.3.21 A closely related GRSU study during the present reporting period dealt with cloud cover considerations in relation to the making of crop inventories from LANDSAT data. In applying this methodology to a cropland inventory in Kern County, June 1 to September 30 was judged to be the optimum time period to acquire imagery. To study the utility of single versus multiple satellites, cloud cover probabilities were calculated for 1 to 3 satellites each on a different 18 day cycle. For the semi-arid San Joaquin Valley it is 99% probable that up to 3 usable dates of LANDSAT imagery will be available in any year between June 1 and September 30. This high probability is possible with just <u>one</u> satellite. Cotton inventory and plowdown monitoring requires information between December 15 and June 14 to meet California State Department of Food and Agriculture information needs. Because imagery is required throughout much of the winter and spring (December 15 - June 14) of the year for this inventory, the probability of obtaining 1 to 3 usable dates is considerably lower. In this instance, the use of more satellites or more frequent overpasses would increase the probability of acquiring the $\leq$20% cloud cover information quite significantly.

7.3.22 An additional water-related study currently being undertaken by GRSU deals with remote detection of perched water and salinity. Perched water tables and excessive soil salinity are highly correlated in their spatial distribution, the former being largely responsible for the latter. Due to this relationship, what were previously separate investigations are now reported in an integrated manner.

More specifically, the subject of this research is the various soil factors influencing the creation of shallow "perched" water tables, and associated soil problems, especially salinization. Soil drainage, in general, is being examined but the focus is on perched water tables, specifically those present in Kern County, California. Several methods for remote detection and monitoring can be put forth:

a. direct detection of soil moisture by passive and active microwave systems;

b. indirect detection of soil moisture by thermal infrared systems;

c. surrogate detection in the near infrared region from high altitude photographic mapping of soil types and salinity conditions often associated with perched water tables.

7.3.22.1 The direct detection of soil moisture using LANDSAT imagery has also been examined by the GRSU but due to the sub-optimal wavelength regions currently available (in terms of soil moisture detection) such imagery requires extensive calibration and supporting ground truth.

7.3.22.2 Based on previous research conducted by the GRSU it has been demonstrated that an image created by a passive microwave radiometer is highly correlated ($r = .98$) with the soil moisture of bare soil. This imagery is currently being acquired for GRSU, under contract research by the China Lake Naval Weapons Center. Surface soil moisture distribution patterns could be an important surrogate for identifying near surface water tables. The rationale for this relationship involves both the slower drainage characteristics and the upward movement of water via capillary action.

7.3.22.3 Based on visual examination of recently acquired radar imagery it appears that backscatter associated with surface roughness (i.e. soil texture, crop canopy, row direction, etc.) may influence the radar return to such a degree that the derivation of accurate soil moisture data may be difficult, except for possibly bare soil fields and instances of standing water. A day and night thermal infrared mission covering the known perched water regions of Kern County has also been planned, approved, and currently awaits the operational status of the NASA Ames Thermal Scanner. The rationale behind this overflight is that the surface temperature and/or thermal inertia of soils should allow soil moisture to be estimated. It is anticipated that variations in soil moisture may then prove useful in monitoring the dimensions of perched water table areas in Kern County.

7.3.22.4 The GRSU has previously mapped suspected perched water tables using NASA (1:125,000) color infrared photography. Though encouraged by initial results (i.e. approximately 60% overall accuracy for identifying subsurface water $\leq$20' below the surface), it has been difficult to improve accuracies using such photography. The primary discriminant of near infrared imagery is related to its ability to identify the organic clay soil types (a good surrogate for perched water tables in Kern County) and standing water occurring where the water table extends to the soil surface. Such photography has no direct capability to detect subsurface water.

7.3.22.5 Color infrared photography has proved useful for detecting saline soil conditions in Kern County. Perched water tables are a common cause of saline conditions; therefore, such conditions may prove useful for generally delineating areas with drainage problems.

7.3.23 During this reporting period the GRSU also has studied the feasibility for the remote detection of soil salinity in Kern County. At present, conventional techniques for gathering salinity data in agricultural environments involve costly field sampling procedures. GRSU is developing a remote sensing methodology whereby salinity data may be generated on a per-field basis from high altitude photography. Such data can serve as input to hydrology models by providing an estimate of the amount of water necessary to effectively leach saline soils. This could result in keeping more land in economic production and/or facilitate the prediction of agricultural yield decrement and dollar loss due to salinity. Kern County Water Agency is particularly interested in expanding the present groundbasin model to perform salt balance computations. The initial correlation with conventional ground truth data and the "deviation from normal field density values" resulted in an encouraging positive correlation coefficient ($r = .79$) for 13 intensively sampled cotton fields totaling approximately 1500 acres.

7.3.24 A Santa Barbara County crop type inventory has been initiated by GRSU on a $4,000 matching fund basis with the Santa Barbara County Water Agency. The investigation is attempting to identify problems associated with the accuracy and cost-effectiveness of high altitude and/or LANDSAT cropland and croptype inventories in this non-arid environment. A county-wide ground truth survey of the 1975 field-by-field croptype has been completed as

the initial phase of the project using color infrared aerial photos. This information will serve the dual purpose of providing an accurate data base for:

a. the investigation of the potential of LANDSAT imagery for future cropland and croptype inventories;

b. Phase I of the Santa Barbara County Water Agency's 1975 Water Resource Planning Program which includes a determination of current water demand, as well as a projection of future water demand.

The final product of this study will be the development of a methodology that can be transferred to local agencies for cost-effective cropland/croptype inventories in Santa Barbara County, hopefully from satellite imagery. To this end, a detailed record has been kept of the time, cost, procedure, and accuracies involved. The priority use of crop type data is for water demand prediction but will be utilized in numerous modes by other county agencies.

7.3.25 Research on groundbasin permeability, as reported in Chapter 3 of this Progress Report, was conducted by GRSU personnel as part of a study by the Santa Barbara County Office of Environmental Quality to revise previous estimates of the Goleta Basin's safe yield. The initial stage of this research involved the detailed delineation of permeable and impermeable surfaces on low altitude conventional black-and-white photography. Impermeable surfaces were broadly defined to include roads, parking lots, etc., while permeable surfaces were more specifically categorized as to their type. This information was manually transferred to overlays and automatically measured by a video image analyzer capable of density slicing and digital planimetering. Accuracies and costs associated with this technique have been documented and compared to more conventional approaches.

Trained image interpreters were employed to classify and categorize data present on the black-and-white photography, scale 1/7200. The interpreters were asked to classify the various land uses into four categories, viz. lawns, irrigated agriculture, natural vegetation, and non-permeable surfaces. The procedures developed and utilized in connection with this project proved highly efficient, requiring less than one day of labor to extract all four class area estimates, on a grid basis, for the entire ten square mile study region.

It is concluded that this research has documented an effective methodology to accurately generate quantititive urban ground-basin data useful for determining safe yield values. The extensive amount of accurate data generated by this project from low altitude photography has provided a reliable basis against which automatic techniques, based upon high altitude color infrared photography, can be evaluated. Analysis of the image interpretation results by the cooperating user agency, the Santa Barbara County Office of Environmental Quality, has just begun. As close user-researcher contact has been maintained throughout this study a favorable user response is anticipated. If successful, such approaches will significantly reduce the time and effort involved in generating permeability data, an important aspect in determining urban hydrology dynamics.

7.4.0 In chapter 4 of this progress report remote sensing scientists of the Riverside campus report on their continuing work with respect to water demand.

7.4.1 They have sought primarily to determine the extent to which remotely sensed data sources can provide cost-effective information relative to the demand for water resources. It is in light of the general water resource allocation problems of Southern California that several planning techniques are being applied (by the Riverside group) which rely heavily on NASA remotely sensed imagery. Included are specific investigations which evaluate and demonstrate the use of remote sensing for estimating water demand for the Upper Santa Ana River Basin.

7.4.2 Another important resource investigated by the Riverside group is the Southern California coastal zone where population pressure for housing and recreation competes with any attempt to preserve the ecological balance of a fragile resource. In a way, the coastal zone is just another extension of the complex California water resource management problem.

7.4.3 The use of high altitude remotely sensed imagery to determine long-term water demand through analysis of land use is proving to be most effective. The California State Department of Water Resources (DWR) has, for many years, forecasted long-term water demand by an empirical model that utilizes net land use as the driving parameter. The results of research conducted by our U.C. Riverside remote sensing personnel have both improved the model in accuracy and provided rapid output of results.

7.4.4 The development of water demand information for the Upper Santa Ana River Drainage Basin has led to three related studies.

a. A machine-assisted land use study. (This is necessary because how the land is used constitutes the driving factor in modeling where and how the water is or should be used, as well as how this mix changes through time.)

b. A population-oriented study which entails stratification of the area based on per capita water use and population density.

c. A study of the temporal aspects of water demand for agricultural purposes in this area (as a demonstration, two projects are being carried out, as described in the following paragraphs.

7.4.5 In order to demonstrate the applicability of high altitude (e.g. U-2) sensors for land use data acquisition, a test site was selected by the Riverside group in which a major land use mapping effort was carried out, utilizing NASA high altitude data sources. The purpose of this effort was not only to map the land use but also to systematically organize the information so that areas could easily be calculated, a variety of maps could be drawn and the data base easily updated from subsequent imagery. Preliminary findings show that a single high altitude (NASA U-2) image can replace many low altitude images and yield far less distortion while permitting much faster data reduction to determine water demands in the Upper Santa Ana Drainage Basin.

7.4.6 The development and maintenance of a water demand model requires both current and accurate data about the driving parameters which, in California are land use and population. Changes in long-term living habits are expressed visually by changes in land use. These changes are most discernible by means of aerial photography. Hence a unique opportunity is provided for NASA test platforms, such as the U-2 aircraft, to display their ability to provide data for solving long-term water resource problems. The following 4 phases are currently entailed in this part of the work being done by the Riverside group:

a. Analysis of imagery to obtain a meaningful classification. (Four date, high altitude aircraft CIR imagery, has been adequate to classify all of the land use in the Santa Ana River Drainage Basin to at least the second level of detail, a level adequate for a water demand model that employs land use as the driving parameter.)

b. Statistical compilation of land use acreage. (The most important application of U.C. Riverside's land use mapping for water demand studies is in the

compilation of acreage statistics. Once a polygon delimiting an area of some specific land use has had its vertices identified and encoded into machine-readable form, it becomes a simple, almost instantaneous, calculation to determine the acreage of the polygon. Summaries by land use type, hydrologic sub-unit or any other pre-defined sub-division are obtainable in less than one minute of computer time using an IBM 360-50).

c. Editing and updating. (In order to facilitate the mapping of land use change in the Upper Santa Ana Basin, objectives and procedures have been formulated. The objectives were devised to insure that: 1) current and reliable land use maps are produced quickly; 2) the land use succession can be detected and measured and; 3) the operational procedures and land use classification system are compatible with the land use information system.) The original land use map and the digital land use outline file are readily available for each quad sheet as a result of effort prior to updating. As recent imagery suitable for updating purposes is acquired, a mylar outline of the original land use is produced by the computer at the same scale as the imagery. Land use change is compiled directly upon the mylar overlay which has the original survey plotted on it. The land use outline is then interpreted for change. This procedure of drafting updated information upon the original map requires less production time and reduces the possibility of error during the transferring of data.

d. The making of preliminary cost-benefit estimates. In this phase of the work it was found that:

1. initial map preparation and conversion to machine code requires about .3 man hours per polygon (an average map in this study has 190 polygons) or approximately 25 hours per map. Average plotting and computer processing costs amount to about $140 per map. It is felt that these figures represent the same time/cost factor as that required for manual land use data compilation. The figures do not include data gathering, where remote sensing far exceeds ground survey methods in efficiency.

2. Cost-benefits begin to apply when (once in machine form) the data are analyzed, cross correlated with other data, used to produce statistics such as acreages or population densities, and/or used to produce maps with various scales and shadings. For example, acreage calculations are essentially "cost-free" at this point.

3. Cost-benefits are likely to be greatly increased when updating and editing procedures are performed. Preliminary studies indicate that approximately 20 man-hours will provide machine input data for a map update where normal manual updating procedures are likely to require upwards of 200 hours. For this one study area alone such savings should be multiplied by 30 maps, giving a total savings of 5400 man hours.

4. The interest by the California Department of Water Resources, (DWR), was not only in our study of the machine-assisted processes, but also in determining what is the relative cost in hardware to place each district into operation on a machine-assisted basis. The minimum starting cost for hardware was found to be $15,000.

7.4.7 Population studies related to water demand were made by U.C. Riverside's remote sensing scientists during the present reporting period. These were of importance because, for estimating present water consumption, DWR utilizes population data and water delivery data for service districts to arrive at a per capita water use statistic. Over time, these statistics yield water consumption trends which may then be used to extrapolate future water demand. This technique cannot be applied to agricultural water use because population has no relevance. For purposes of urban water demand estimation, however, this procedure is proving quite useful, even though it has limitations for some planning purposes because of the aggregated nature of the data.

a. One aspect of this study addressed the need to analyze water use on a per capita basis. It employed a combination of data from the decennial census and high-altitude color infrared imagery. At least one value of this combination of data is the amplification of its geographic component. For example, it is be useful to show not only the extent of each census tract, and its population aggregate, but the actual area within each census tract that is occupied by various forms of land use. The use of high speed computers and readily available software, coupled with remotely sensed land use patterns, allows rapid and accurate calculation of land area used versus land not used. In addition, the enumeration of areas occupied by any of several land uses can be accomplished efficiently and may be delivered in a per capita format.

b. Population density was calulated by using a combination of census data and imagery for a sample portion of the Santa Ana River Drainage Basin. The sample study involved the interpretation of the areas of residential land use from high altitude CIR imagery. The residential pattern for each census tract was then converted into a computer-compatible format by digitizing the polygon boundaries for residential and non-residential areas for the entire study area. An automated mapping program was then used to produce both the map and the area calculations for each census tract, and for each continguous residential area within that tract. The residential area was then used instead of the census tract area to calculate residential population density within that census tract. The advantage gained is that the actual areal location of water demand is now known. The locational per capita data can be updated periodically by comparison of the mapped patterns with more recent imagery to check for changes in the residential pattern. Then, by applying density figures to changed areas, a new population estimate can be made.

c. The unique element of this procedure is that it is sensitive to population migration. In areas of doubt, ground truth is required to determine the exact nature of the residential change. Citrus was chosen because of its regionally significant consumption of land and water resources.

Temporal and spatial trend analysis of the citrus crop commenced with the establishment of a base time period and a recent time period in which changes could be detected. The time between the surveys needed to be long enough to reflect the urban growth influence on a permanent crop. Black-and-white photo mosaics of portions of Riverside (1959) and San Bernardino (1961) Counties provided a base period at the time when urban sprawl was beginning. NASA U-2 imagery at a scale of 1:130,000, flown on two dates (October 16 and December 10, 1974) was used for a survey of the present pattern. Areas of citrus were outlined on reference maps made from USGS 15' Quadrangles. Maps of the two time periods were then combined, digitized and processed to obtain area statistics and establish a locational base for future investigations. The Ontario-Pomona area contains much urban fringe and (as presumed) the map reveals a decrease. This decrease amounts to 8303 acres (3360 hectares) between 1959 and 1974. This procedure is presently being carried out for all other relevant areas of the entire basin.

7.4.8 Still another aspect of the U.C. Riverside remote sensing work entailed estimation of the inactive field period. The presence or absence of irrigated agriculture in a particular region represents information which is very important in DWR water demand estimation models. In Southern California, multiple cropping practices give rise to a condition in which the use of a single sample to estimate irrigated agricultural lands may lead to an erroneous estimate. Remote sensing, with its rapid inventorying and synoptic sampling capabilities, enables the use of multiple samples. If these aerial samples are taken at selected times throughout the year, a more accurate determination of the average requirement for irrigation water is made possible.

Research involving estimation of inactive fields is being directed toward: a) defining the most appropriate time of year for overflights; and b) defining and evaluating interpretive signatures for high altitude and satellite imagery.

7.4.9 In our Annual Report of May, 1975 we proposed that a portion of our research this year would consist of studies by the U.C. Riverside remote sensing scientists involving the coastal area of southern California. This was approved and two areas of study have evolved from this proposal: a) studies relating to environmental impacts of human activity within the coastal zone, and b) studies relating to the physical features of the coastal zone which are being modified by human interference with the natural processes. The primary objective of the proposed research in the coastal areas has been to seek out problems of concern to public agencies and then to determine the extent to which remote sensing can provide data that will assist in the solution of such problems.

One aspect of these studies entailed our determining the extent to which remote sensing facilitates the analysis of traffic congestion resulting from recreational activity in an intensively used area. This phase of our study used as a test site the Malibu corridor.

A second aspect of these studies dealing with coastal processes, is just in the planning phases. A minor study is concerned with the morphology of beach cusps and adresses part of the major problem of beach sand erosion. Two primary objectives of a related U.C. Riverside remote sensing study on the role of storage, damming control and use of local and imported water are (1) to determine the impacts that diminish coastal lagoons and (2) to evaluate the far reaching environmental effects. Any truly integrated remote sensing study of California's water resources should not overlook these important considerations. Findings of this recently initiated work will be reported in our May, 1976 progress report.

7.4.10 A study was made by the U.C. Riverside remote sensing scientists in an effort to determine what problems are associated with traffic and also with recreational use in the Malibu corridor. The established usefulness of U-2 imagery for land-use based studies initiated an investigation into the suitability of this imagery as an aid in the development of a simulation model for the analysis of activity change in a coastal area. The purpose that was envisaged for this model is twofold. First, by selection of appropriate data retrievable from the imagery, a parameterized coastal interaction zone might be developed. It is proposed that this model include (but not necessarily be restricted to) land use aspects associated with areas devoted, respectively, to housing, commercial and industrial use, transportation, and recreation. Secondly, from the land use data, analysis of subsequent imagery, and other data sources, proposed activity changes (e.g. specific land use, transportation corridors, recreation facilities) might be analyzed to project possible impact within the established coastal interaction zone.

A high degree of interest in this phase of the U.C. Riverside remote sensing-based work was exhibited by each of the following agencies, all of whom are concerned with traffic congestion in the Malibu area: the California State Department of Transportation (Caltrans); the Southern California Association of Governments (SCAG); the Los Angeles County Department of Roads; the City of Los Angeles Planning Department; and the City of Santa Monica Planning Department.

In conjunction with this study, efforts have been directed by our UCR remote sensing scientists to beach use (available recreation area capacity as opposed to actual use) and correlated parking facility availability. The general approach entailed in our efforts to maximize the usefulness of remote sensing in connection with this Malibu Corridor Traffic and Recreational Use Study is as follows:

a. establishment of individual beach morphology

b. establishment of parking availability for each of the defined beach areas

c. establishment of the number of beach users for particular beaches

d. relation of observed densities to availability of facilities, proximity to heavily populated residential areas, and perceived area traffic congestion problems.

7.5.0 As documented in Chapter 5 of this progress report, the Social Sciences Group that is participating in this integrated study has established good working relationships with the California Department of Water Resources, the State Water Control Board, and the various federal agencies that are involved in California water management. In fact, members of the Social Sciences Group have been permitted to sit in on key meetings so as to observe at first hand how issues are addressed and plans assessed. Officials of the various agencies, departments, and divisions have given generously of their time for personal interviews and have supplied our group with data, records, and other valuable source material. This high level of cooperation comes about because of the express interest on the part of the State in helping us gain a broader and deeper comprehension of their concerns so that ultimately our research effort will be available and useful to them.

7.5.1 The first section of Chapter 5 reviews the Department of Water Resources' new water action plan. The second section of the report considers the functional relationships between water and other basic resources--land, energy, and the like. A related part of this second section deals with the jurisdictional relationships among the various agencies responsible for resource management at the state level and those existing between State and Federal levels. It is at this point that there occur some of the most difficult and perplexing problems besetting the management of water. There follows a section which is devoted to the ways in which environmental impact is assessed.

7.5.2 An important element with respect to the future management of California's water resources was the recent publication by DWR of a revised "Water Action Plan". Suggested in that plan are improved agricultural practices, modernization of water distribution systems, revision of building codes, analyses of industrial and agricultural water uses, and effects of pricing on water use. Ultimately, there will emerge from this effort identification of possible methods of water conservation, with an assessment of the pro's and con's of each, specification of locations, typical and general, of potential applications, calculations of possible savings in water, and estimation of likely means, costs, and impacts of implementation. Included in the latter category are effects on local water demand and supply, water quality, waste disposal, the environment, and the economy.

7.5.3 It is anticipated that the management of California's water resources soon will be modified in the light of various considerations that are of both socio-economic and technological significance. As examples of the typically socio-economic, we find reference to land-use planning, water pricing practices, social impacts of water and energy conservation measures, and the possible reduction in water demand brought about through change in crop patterns. In addition, increased attention soon will be given to recommendations regarding environmental protection, fish and wildlife preservation, recreation requirements, and water quality standards and also to the risks of dry year recurrence.

7.5.4 Our Social Sciences group notes that, in the East Side San Joaquin Valley, the mining of ground water, with the consequent lowering of water tables and rising of pumping costs and energy consumption, is a major concern. Because of consolidation of aquifers and increased concentration of salts in lower water volumes, land subsidence is a severe threat there. In view of the current and increasing overdrafting of ground water supplies, various alternative plans will be considered including the importation of water via canals and the employment of more stringent conservation efforts. These will be appraised, there having been taken into account a revised scenario for water requirements as limited supplies and environmental, social, and economic desiderata are realistically evaluated.

7.5.5 Drainage problems, as reported by our Social Sciences group, are especially prevalent in the West Side San Joaquin Valley, where disposal of agricultural waste waters is a central concern. Due to soil conditions, saline return flows are trapped near the ground surface and ultimately could so reduce potential for the growing of healthy agricultural crops that this area of fertile farmland could be ruined.

7.5.6 The South Bay-Central Coast Area faces realistic reassessment of its supply and demand situation. At present relying on ground water with some importation, the region may need to re-examine earlier projections as to population growth and agricultural expansion. Here, as in other districts, quantities and timing of need for water deliveries might be found to be sensitive and responsive to revised water pricing policies and more determined conservation and reuse measures.

7.5.7 Maldistribution, poor quality of local surface water, and deterioration of ground water quality are problems high on the agenda of the Southern District (San Luis Obispo and Santa Barbara Counties). One of the basic questions raised in this as in the other areas has to do with the economic, social and environmental implications of not meeting water demands as projected earlier.

7.5.8 As reported by our Social Sciences group the South Coastal Area is probably supplied with sufficient water until the year 2000 , but if recent population and industrial development forecasts are reliable that area could benefit even now from better water management practices, e.g., greater utilization of reclaimed water, more effective use of ground water, water exchanges, and reduction in demand through conservation.

7.5.9 The DWR is inquiring into policies and operational theory underlying the State's two major water systems, viz., the State Water Project and the Central Valley Project. In coordination with studies being conducted by the Bureau of Reclamation, the DWR specifically plans;

a. to develop estimates of water yield;

b. to locate additional water exchange possibilities between project systems;

c. to devise methods for more utilization of ground water when surface water supplies are deficient;

d. to run various sensitivity analyses to ascertain physical opportunities and socio-economic and environmental effects of changing project operational criteria with different balances among project purposes, the objective being an enhancement of instream water values; and

e. to calculate the degree of risk associated with modifying traditional deficiency norms for project operation during critical dry periods.

7.5.10 It is probable, according to analyses made by our Social Science group, that the two most pressing water management problems in the state of California are:

a. the Peripheral Canal and other ways of meeting water requirements for the Delta and other areas, and

b. definition of the need for, and timing of, supplemental yield facilities for the State Water Project.

7.5.11 Aspects of water management that have continued to be the focus of research by the Social Sciences Group since the inception of the University of California Remote Sensing Project are:

a. the functional relationship between water and other resources;

b. water as a factor in and as affected by growth and development in the society;

c. jurisdictional and bureaucratic relationships and the way in which they impinge on water management;

d. water in its relationship to the total environment and as assessed through environmental impact studies; and

e. decisions regarding water and the processes by which public participation is invoked.

7.5.12 A major part of Chapter 5 of this Progress Report deals with water management interrelationships, with special emphasis on how DWR concerns relate to those of other resource management agencies. In this part of its report, the Social Sciences group attempts to delineate some of the main functional and jurisdictional areas that affect water management decision-making in California.

In this, as in other sections, the point is made that the DWR appears to be shifting emphasis from a posture of resource developer to that of resource manager. This metamorphosis has significant implications for an information-rich technology like remote sensing. Although both development and management functions require information regarding costs, environmental impacts, and so forth, the management function, in particular, requires information of a continuous and periodic nature for monitoring the performance of a resource management system. Accurate and timely monitoring becomes all the more important when one is trying to stretch a given resource over more users (e.g. water conservation), or to measure negative side effects of stretching that resource too far (e.g. pollution, salt water intrusion, subsidence). Satellite remote sensing technology, in combination with airborne and ground-based sensors, is already capable of augmenting substantially the repetitive information needed to monitor and manage many aspects of California's water and water-related resources.

7.5.13 According to our Social Sciences group, water resource management in California is being profoundly influenced by major changes in the larger social environment. The orientation toward growth and expansion of water resource facilities, prevalent in the 1940's and 1950's, appears to be undergoing modification as the result of new perceptions developed in the 1960's and 1970's. At least three such major changes seem identifiable:

a. an awareness of new publics;

b. an awareness of negative environmental side effects;

c. an awareness of resource constraints.

7.5.14 In Chapter 5 a substantive discussion is given of water management interrelationships within three resource areas: water, energy, and land. Recent changes referred to in the preceding paragraph are

being translated into policy.

7.5.15 A final major section of Chapter 5 deals with environmental assessment in relation to public participation. Central to that analysis is the National Environmental Protection Act of 1969 (NEPA). Its primary purpose is to encourage full disclosure of the environmental consequences of proposed major federal actions, thus alerting the government and public to the environmental risks involved. NEPA spawned and is still spawning a host of offspring in state and local governments across the nation. The California Environmental Quality Act (CEQA), enacted in 1970, is the oldest and one of the most extensive of the state programs. As a result of these legislative measures, decisions of many types, and particularly those involving the use of scarce resources, are being subjected to more comprehensive forms of evaluation. Environmental impact reports, for example, appear to be expanding to resemble more closely technological assessment studies. Cynical observers might attribute this trend to obstructionist tactics of environmental zealots or to the newly-vested interests of EIR consultatants. Yet one should be cautious about allowing too narrow an interpretation of events to obscure what otherwise might actually be a genuine cultural reorientation in philosophy toward the environment. Distinguishing clear signals amid the social noise is seldom an easy task, according to our social scientists.

7.5.16 Our Social Sciences group asserts that technology assessment methodology itself has undergone considerable change and controversy as it has evolved over the last decade and cites much evidence to support this assertion.

7.5.17 As our Social Scientists seek to map the social landscape they also report that they perceive

a. A growing appreciation of the interrelated nature of public policy issues. (Local and national problems concerning energy, diminishing resources, and pollution of air, water, and soil intertwine with global crises concerning armaments, food, population, and capital formation.)

b. A shift involving disenchantment with traditional quantifications. ("Unhappy clashes with aroused groups of ecologists have proved that when a dam is being proposed, kingfishers may have as much political clout as kilowatts".)

c. A growing realization that search for a single method for carrying out assessments has been misguided. ("There is no general method, methodology, or technique yet developed for conducting a technology assessment.")

7.5.18 There is an increasing desire to ensure that there is adequate "public participation" as a continuous two-way communication process designed to: (1) promote full public understanding, (2) keep the public fully informed, and (3) actively to solicit opinions, perceptions, and needs from all concerned citizens.

7.5.19 Our Social Sciences group reports that a recent review of public participation in 45 water resources projects showed that the public hearing was by far the most frequently used technique for involving the public in decision-making processes. Other approaches included task forces, committees, advisory boards, workshops, newsletters, surveys, and various combinations of these techniques. Although some of these methods encourage greater public involvement, they usually mean a corresponding increase in agency time, money, and personnel costs. In addition, experimentation with different participation processes is often inhibited by legal requirements that public hearings be held.

7.5.20 Limitations of the public hearing process are well known. They include notification of the hearing's time and place, domination of the proceedings by vested interests and agency experts, limited opportunity for informed involvement by interested individuals, and public apathy. The problem of encouraging meaningful involvement often splits into two subproblems: first, how to arouse citizen concern, and second, how to organize that concern.

7.5.21 Observation over the past year of numerous public hearings--mostly related to water resources agencies--has prompted our Social Sciences group to conclude that California agencies are not exempt from the usual set of difficulties that afflict public participation processes. In addition to the foregoing limitations, there is a tendency for the hearing publics to polarize into two camps consisting of "land users" (those who control the land for agriculture, industry, or development purposes) and "non-land users" (those who exercise little or no direct control over the land). Nationally, the ratio between non-land users and land users has been estimated at 9 to 1. The non-land user group has tended to become the one which initiated the request for land-use planning and regulation, while the land user group is often identified as trying to channel efforts away from planning and regulation into programs incorporating economic incentive.

7.5.22 In summarizing its observations with respect to water resource management in California, our Social Sciences group asserts that it perceives three significant recent developments:

a. a changing emphasis from resource development to resource management;

b. an increasing emphasis on comprehensiveness in water resources planning, including:

   (1) an attempt to increase meaningful public participation;
   (2) an attempt to relate to other functional areas;
   (3) an attempt to integrate more effectively with other jurisdictional areas, and;

c. a growing appreciation of the need for anticipating and assessing the environmental effects of new projects programs, and policies, coupled with a growing awareness of the inherent limitations of environmental assessment studies.

7.5.23 As the Social Science group continues to review the various methodologies for technology assessment and environmental impact, it plans to continue exploration of the activities and decision processes that interface with water resources management. This sort of peripheral vision is essential if we are to discover and assess how remote sensing technology can be employed to enhance the decision environments of resource management agencies. One thing is clear: it is combinations of users, uses, and data sources that will produce many of the future remote sensing applications.

Hopefully, the group will be able to include testimony by the users themselves regarding the application of remote sensing technology to their decision processes because, in the final analysis, it is the quality of resource management decisions, and their societal consequences, that all of us who are engaged in this integrated study are interested in improving.

7.6.1 One of the special studies appearing in Chapter 6 of this progress report describes the work done by two participants in this integrated study, Coulson and Walraven of the Davis campus, in developing a video polarizer for remote sensing of earth resources.

7.6.2 Their video polarizer system consists of a three-vidicon television array in combination with appropriate signal processing electronics and a color television monitor. Its primary use is for sensing and displaying the intensity and polarization information in natural landscape scenes. As demonstrated by the two photographs accompanying this special study, differences in both hue and saturation can be seen through the use of this equipment.

7.6.3 It is anticipated that this, or a similar system will be a valuable aid in discriminating among various types of surfaces in future remote sensing studies of earth resources. For instance, it is

known that various types of agricultural crops and wildland vegetation types have different polarization characteristics and that the polarization of light reflected from a given bare soil is a function of the amount of surface moisture which that soil contains. The present system has the capability of capitalizing on these characteristics.

7.6.4 Another special study appearing in Chapter 6, prepared by Algazi and Suk, considers the frequency weighted least-square design of finite duration filters, in one and two dimensions, both continuous and discrete. While this work was supported in part by our NASA Grant, some support for it also was provided by Algazi's NSF Grant.

7.6.5 The potential significance of this work, as discussed in Chapter 6, lies in its usefulness in designing a series of filters, each of which is optimum for discriminating some particular resource feature from all others with which it commonly is confused. The technique developed by these two investigators is different from, and in certain respects decidedly superior to, techniques developed previously by other investigators who had essentially the same objectives in mind.

7.7.0 In light of the work done during the present reporting period, as summarized here in Chapter 7, our Progress Report concludes with Chapter 8, in which we present a statement of the work which the various participants in our integrated study propose to perform during the period May 1, 1976-April 30, 1977.

7.8.0 The proposal contained in Chapter 8 is based on three important considerations:

a. that, by April 30, 1977 our group will have brought to a satisfactory state of completion essentially all of the additional work which it considers necessary and appropriate for the group to perform under the grant on water resources;

b. that during the coming year, consistent with the above, major emphasis will be placed on our preparing a "Procedural Manual" which will set forth in clear, step-wise fashion, the procedure that should be followed in collecting, analyzing, storing, retrieving, and using remote sensing data, the better to satisfy the informational requirements of those who manage water resources, and;

c. that essentially the same team of co-investigators, campus-by-campus, will be involved in this work with one notable exception: Dr. Coulson, et al , in conformity with long term plans that were agreed upon three years ago, will no longer be formally participating in our grant-funded work even though it is mutually recognized that much of his future work is likely to have great potential applicability to the use of remote sensing as an aid in the inventory and management of California's earth resources complex.

CHAPTER 8

Proposal for Work to be Performed during the Period May 1, 1976-April 30, 1977

INTRODUCTORY NOTE:

As requested, briefings were presented to the NASA monitors of this grant[*] on May 15-16 and again on September 23-24, 1975. The briefings placed emphasis on (1) work recently performed and (2) work proposed for the funding period May 1, 1976 - April 30, 1977. As a result of those briefings the following agreement was reached between the NASA monitors and the participating U.C. scientists, subject to approval by authorities at NASA Headquarters in both the Office of Applications and the Office of University Affairs:

The primary objective of work that is to be performed during the funding period May 1, 1976 - April 30, 1977 is to bring to a satisfactory state of completion those studies dealing with the applications of remote sensing to California's water resources. More specifically, by the end of that period, investigations by U.C. scientists will have been completed relative to the usefulness of remote sensing-derived data as input to certain water-related forecasting models, viz. the models currently being used in California to forecast water supply and water demand.

In arriving at this agreement, the NASA monitors and the U.C. scientists acknowledged that full scale operational tests still would remain to be performed in order to establish the cost-effectiveness of these supply and demand models. However, it was agreed that the burden of performing such tests would need to be borne after April 30, 1977, primarily by personnel of California's various water resource management agencies such as the California Department of Water Resources, the Kern County Water Agency and the Los Angeles Metropolitan Water District, with only limited involvement by U.C. scientists.

The parties to this agreement also acknowledged that despite the foregoing, even after April 30, 1977, some continuing but limited participation by U.C.'s remote sensing scientists probably would be called for relative to another aspect of model development applicable to California's water resources, viz. the development of more sophisticated models. Such continued participation would be in keeping with earlier proposals which had consistently acknowledged the probability that more nearly optimum (and more sophisticated) models for forecasting water supply and demand eventually could be developed, but only after California's various water resource management agencies had gone through

[*] This grant is entitled "An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques".

the interim process of accepting the remote sensing-based modifications of their existing models. Realization of this fact had prompted the conclusion that the more nearly optimum models would be slower in evolving. Furthermore, by their maximizing the usefulness of remote sensing-derived data, such sophisticated models probably would be quite different in format than any existing models. Consequently it was recognized that, in the interest of providing the necessary expertise and continuity, a limited amount of additional work leading to the development of such models would need to be conducted by the U.C. remote sensing team even after April 30, 1977, as previously advocated. The milestone charts comprising Figures 1, 2, and 3 are in keeping with this concept.

In addition, in the course of the previously-mentioned briefings the following agreements were reached, which likewise were recognized as being subject to approval by authorities at NASA Headquarters:

(1) For two reasons, work being done under the grant by Professor Coulson, et al, at the Davis campus would be terminated as of April 30, 1976:

(a) by that date his investigations on atmospheric effects in image transfer and also his work in developing a video polarizer system will have been successfully completed, and

(b) by that date the California Energy Commission almost certainly will have seen fit to fund at a suitably high level numerous practical applications for the work which Coulson et al have done to date (under the grant) on albedo of the earth's surface and on related solar energy phenomena. (Consistent with that prediction, U.C. has just been funded by that Commission in the amount of $80,000 to permit Coulson to perform the initial phases of such practically-oriented work.)

(2) Continuing efforts would be made by all other members of our U.C. team to obtain substantial support for developing practical applications of our findings to date under the grant. (At the time of this writing, it appears quite probable that the California Energy Commission, primarily because of its interest in the energy relationships of water, will fund collectively, the Berkeley, Santa Barbara, and Riverside components of our team in the amount of $100,000 to $200,000 next year, <u>provided</u> that "matching funds" from NASA for the conduct of related basic research will be provided through renewal of our grant.)

(3) During the period May 1, 1976 - April 30, 1977, the U.C. team would, in addition to the above, investigate the extent to which decisions made relative to the management of California <u>water</u> resources might be altered when viewed in a larger framework. The concept which prompted this recommendation was identical with that which, at the time when our study was being initiated in 1970, had prompted the NASA funders and the U.C. scientists to agree that it should bear

the following broad title: "An Integrated Study of Earth Resources in the State of California, Using Remote Sensing Techniques". Specifically, decisions which appear to be optimum when one considers only the management of water resources, may be revealed as being unsatisfactory when one considers the consequences of such decisions in terms of the entire "resource complex", including the timber, forage, soils, minerals and recreational potential of areas affected by the decision.

All of the foregoing considerations are reflected in the brief statement which follows relative to work which our University of California scientists propose to perform during the period May 1, 1976 to April 30, 1977 under the NASA Grant. That statement and the associated Figures should be compared with two earlier statements in order to document the fact that, from the outset, our integrated study has proceeded in very close conformity with a master plan as set forth in (1) the initial proposal which led to the funding of our integrated study on May 1, 1970, and (2) the revised proposal, dated September 30, 1973, which led to the emphasis that has since been placed on remote sensing as an aid to the management of California's water resources.

SPECIFIC ACTIVITIES PROPOSED FOR THE FUNDING PERIOD MAY 1, 1976-April 30, 1977

A. WATER SUPPLY STUDIES

Under our NASA grant, the Remote Sensing Research Program (Berkeley), the Algazi Group (Davis) and the Hoos Social Sciences Group (Berkeley) continue to be involved in studies on the usefulness of remote sensing in forecasting and monitoring water supply in selected watersheds of northern California. Continuing analysis of hydrologic model structure, inputs and performance is being conducted by the former two groups. Performance is being documented with respect to "conventional" and to "conventional-plus-remote sensing" data inputs. Both the Remote Sensing Research Program (RSRP) and the Hoos Group are quantifying costs and benefits associated with current and potential remote sensing-aided hydrological model applications.

This work is set in perspective by a continuing analysis of the California Water Project as a system from the standpoint of both physical and economic phenomena. It is apparent from the current analysis of future product importance in the California Water Project, that issues other than water quantity, such as water quality and power generation, will become increasingly significant. The water supply investigating groups funded under the present grant propose to investigate, during the period May 1, 1976 - April 30, 1977, the feasibility of using remote sensing techniques in the measurement and analysis of these other water-related parameters.

The RSRP, Algazi, and Hoos groups are conducting remote sensing water supply application studies in an integrated manner. Figure 1 gives the time schedule by subtask for this effort. It should be noted with reference to this figure that studies documenting remote sensing's potential economic impact are now significantly under way.

1. The Algazi Group - (Davis Campus)

By means of continued interaction with personnel of California's Department of Water Resources, on the one hand, and with the RSRP and Hoos groups at Berkeley, on the other, members of the Algazi group propose to engage in the following specific activities.

(a) Continued Water Model Definition and Performance Documentation

One of the objectives of this work is to verify that the model used or being developed closely simulates the watershed, itself, so that meaningful sensitivity tests can be conducted and evaluated. Emphasis will be placed on the use of remote sensing to measure parameters that will permit a more accurate determination of (1) the maximum water holding capacity of each portion of a given watershed and (2) the water content actually present in each such portion at any given time. Through the operation of the hydrologic model, these quantities in turn determine the runoff of the watershed. Model parameters being evaluated include precipitation, evapotranspiration, upper and lower zone water holding capacity, upper and lower zone free water, and upper and lower zone tension water.

(b) Sensitivity Analysis of Critical Parameters

Emphasis will be placed on determining the percentage change in performance indices based on daily volumetric runoff with a given percentage change in one or more of the above-mentioned parameters, watershed-by-watershed.

(c) Continued Development and Testing of Remote Sensing Techniques

This work divides into two parts. The first part, performed in close cooperation with personnel of the RSRP, is a study and simulation of hydrologic parameters, such as evapotranspiration demand, acquired by remote sensing, on the operational use of the hydrologic models by the Sacramento River Forecast Center. This work is detailed in section 2 which follows. The second part of the work is the development of techniques for the forecast of snowmelt using remote sensing data obtained by the Landsat and NOAA satellites.

(d) Determining Cost of Information Gathering Using Remote Sensing Techniques

Section 2 provides details relative to this point joint effort also.

2. The RSRP Group - (Berkeley Campus)

The continuing work of this group will include the development and testing of cost-effective, remote sensing-aided procedures for quantifying snow areal extent, snow water content, evapotranspiration (major world-wide water loss mechanism), and watershed impervious surface area (important in water runoff timing). The impact of each of these information components

on water yield forecasting will be determined. In addition, a cost analysis will be performed to determine what cost reductions in water yield estimation can be achieved through the use of these remote sensing-aided techniques. Finally, a program of technology transfer will be initiated to allow for the testing and possible incorporation of these techniques within the California Cooperative Snow Surveys Program and in possible other organizations (e.g. the Sacramento River Forecast Center).

Consistent with Figure 1, the specific tasks will entail:

(a) Continued Water Model Definition and Performance Documentation as detailed in the preceding section.

(b) Sensitivity Analysis for Critical Parameters as detailed in the preceding section

(c) Developing and Testing Remote Sensing Techniques
In this phase of the work both manual and automatic analysis techniques will continue to be employed, as emphasized in Figure 2.

(d) Determining Costs of Information Gathering Using Conventional and Remote Sensing-Aided Methods (see f, below).

(e) Comparing Remote Sensing Techniques with Conventional ones (see f, below)

(f) Analysing Cost-Benefit Inputs on Society Resulting from Changes in Water Supply Information due to Application of Remote Sensing Techniques.

These last 3 phases of the work (being done jointly with Hoos et al) may entail further testing and refinment of ways in which remote sensing can best be used. This work will be required if adequate responses are to be made to requests by users for appropriate technique modification to allow most efficient interfacing with their current systems. Such an effort will require application of certain of these techniques to previously studied watersheds, in order that our findings can be based on a larger (more dates) and more detailed data record. It also will involve application of these procedures to other watersheds to quantify and control the water yield forecast performance expected in different environments. In addition. an expanded follow-on program of technology transfer will be necessary to ensure adoption of these remote sensing-aided procedures by water supply forecasting organizations. Ideally, the further procedure refinement and technology transfer programs would start during the May 1976 to April 1977 time frame, and would be completed in following funding periods.

Work Item	Investigators	Period of Performance: Present Funding Year (M J J A S O N D J F M A)	Next Funding Year* (M J J A S O N D J F M A)
1. Continued Water Model Definition and Performance Documentation	Algazi RSRP		
2. Sensitivity Analysis for Critical Parameters in Water Supply Models	Algazi		
3. Develop and Test Remote Sensing Techniques	RSRP Algazi		
4. Determine Costs of Information-Gathering Using Conventional and Remote Sensing-Aided Methods	Hoos RSRP Algazi		
5. Compare Remote Sensing Techniques with Conventional Ones. Draw Conclusions Regarding Cost-Effectiveness	Hoos RSRP		
6. Analyze Cost-Benefit Impact on Society Resulting from Changes in Water Supply Information Due to Application of Remote Sensing Techniques	Hoos RSRP		

Figure 1. Chronological Plan for the Assessment of Water Supply by means of Remote Sensing.

*Beginning on May 1, 1975.

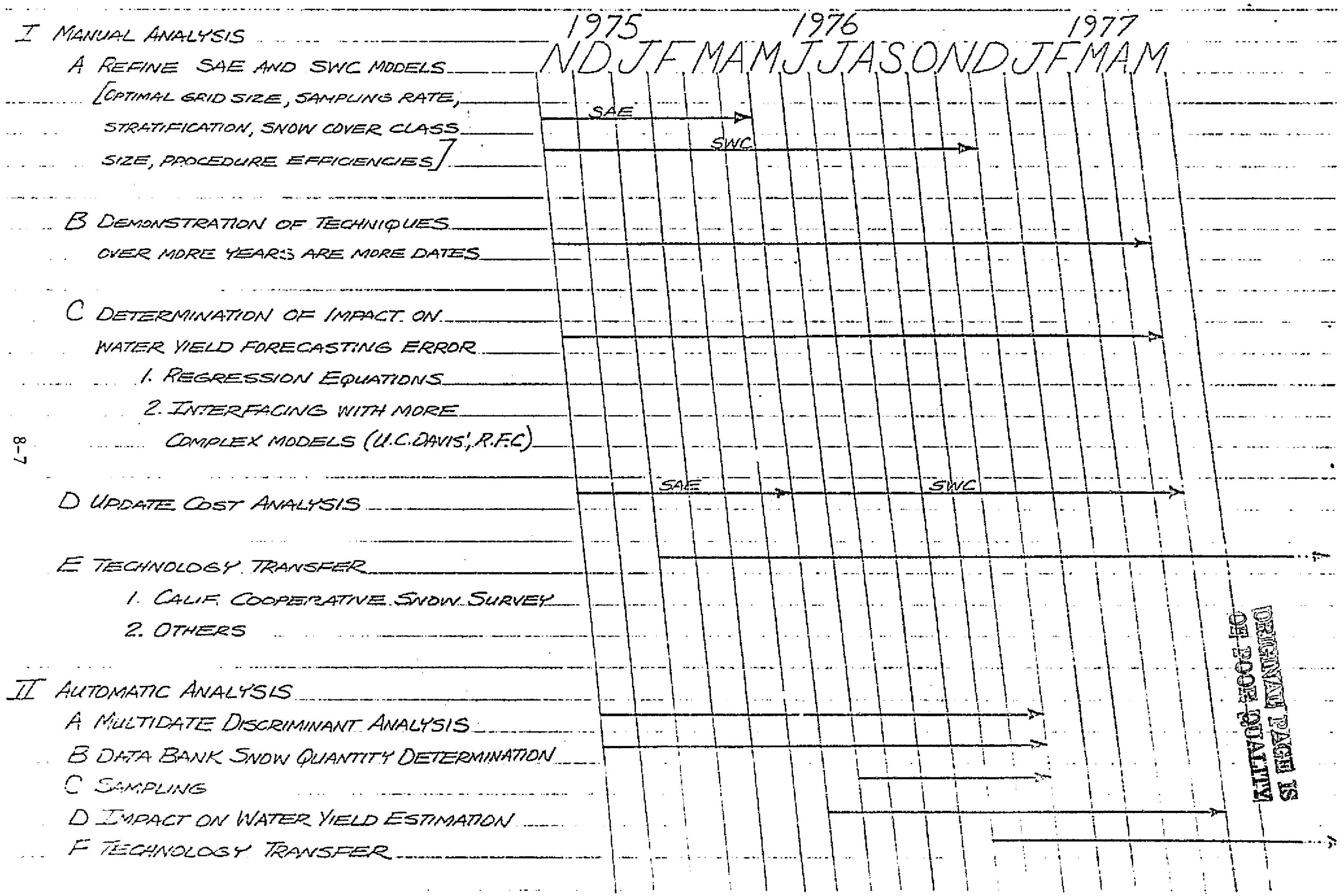

FIGURE 2. Developing and Testing Remote Sensing Techniques for Snow Quantification (Snow Areal Extent [SAE] and Snow Water Content [SWC])

3. The Hoos Group - (Berkeley Campus)

Continuing activities of the Hoos Social Sciences Group are devoted to an overriding objective: to discover how remote sensing information can be used to enhance the decision environm t of resource management operations. Toward this goal, the Hoos group endeavors to bridge the gaps between the developers and the users of space technology. Close integration of technical and social concerns is a key element in this group's work, exemplified by the joint tasks shared with the remote sensing groups at Berkeley and other campuses. With respect to water supply issues, work of the Hoos group will include the following tasks:

(a) Analyze the Framework in which Water Supply Decisions are Made and Implemented

Decisions provide the link between information about resources and resource management action. Yet this link is often blurred by a dynamic web of extraneous socio-economic and political influences. The Hoos group plans to continue its efforts here to delineate those changing social forces and information requirements that impinge on decisions of water resource policy-makers and managers.

(b) Identify the Decision Points Most Amenable to Augmentation by Remotely-Sensed Information

This phase of the proposed work is actually a "user-oriented" technology assessment designed to discover those places where the addition of less costly, more accurate, or more timely information is likely to achieve the greatest improvements toward the accomplishment of water resources management objectives. It involves determining the costs of information-gathering under conventional and remote sensing-aided methods as well as anticipating factors which might influence receptivity toward new information sources.

(c) Evaluate the Potential Social Impacts Resulting from Changes in Water Supply Information Due to Application of Remote Sensing Technology

Here, the Hoos group's resource economist will examine the assumptions, data, and intangibles commonly associated with evaluating the utilization of remote sensing technology in the water resource domain. The intended result is to penetrate beyond the superficially "objective" brand of cost-benefit and cost-effectiveness analyses that have characterized many past technology assessments and to arrive at a more meaningful rationale and set of conclusions.

B. WATER DEMAND STUDIES

Under our NASA grant, the Geography Remote Sensing Unit (Santa Barbara) the Bowden group (Riverside) and the Hoos group (Berkeley) continue to conduct studies on the usefulness of remote sensing in forecasting and monitoring water

demand in selected areas of southern California. Continuing analysis of hydrologic model structure, inputs, and performance is being conducted by the first two of these three groups. Performance is being documented with respect to both "conventional" and "conventional-plus-remote sensing" data inputs. All three groups, working in concert, are attempting to quantify costs and benefits associated with current and potential remote sensing-aided hydrological model applications. This work is set in perspective by a continuing analysis of certain components of the California Water Project insofar as they constitute parts of an overall system from the standpoint of both physical and economic phenomena.

The three groups are conducting their remote sensing water demand applications studies in an integrated manner. Figure 3 gives the time schedule by subtask for this effort. The role which each of these groups would continue to play with respect to each of these subtasks during the period May 1, 1976 - April 30, 1977 is as described in the following sections:

1. The Geography Remote Sensing Research Unit - (Santa Barbara campus)

(a) Continued Water Supply Model Definition and Performance Documentation

The primary model dealt with by the GRSU is the ground water model which previously had been brought to a certain state of development by the Kern County Water Agency (KCWA). It is proposed that a modified version of this model, as currently being developed by the GRSU-KCWA team, be adapted for computerization at the Santa Barbara campus. Such a measure would greatly facilitate the making of sensitivity analyses relative to the impact of remote sensing-derived information upon water demand predictions.

(b) Sensitivity Analysis for Critical Parameters in Water Demand Models

As with the water supply model, emphasis in this phase of the proposed study would be placed on determining the percentage change in a water demand estimate associated with a given percentage change in one or more of the measurable parameters. Related to this is work currently being done by GRSU relative to "expected information content" (i.e. the anticipated errors resulting from their exclusion) of several variables involved in water demand prediction. Each such analysis is being verified by reference to empirically-derived data. Much earlier in our integrated study, this work generally defined croplands and crop type information as the two single most important variables of concern in those lands of the San Joaquin Valley for which the original KCWA model was developed.

		Period of Performance	
		Present Funding Year	Next Funding Year*
Work Item	Investigators	75 76 M J J A S O N D J F M A	77 M J A S O N D J F M A
1. Continued Water Supply Model Definition and Performance Documentation	Riverside Santa Barbara		
2. Sensitivity Analysis for Critical parameters in Water Demand Models	Riverside Santa Barbara Hoos		
3. Develop and test remote sensing techniques	Riverside Santa Barbara RSRP		
4. Determine costs of information-gathering using conventional and remote sensing-aided method	Riverside Santa Barbara		
5. Compare remote sensing techniques with conventional ones. Draw conclusions regarding cost-effectiveness	Riverside Santa Barbara RSRP		
6. Analyze Cost-benefit impact on society resulting from changes in water demand information due to application of remote sensing techniques	Riverside Santa Brabara		

FIGURE 3. Chronological Plan for the Assessment of Water Demand by Means of Remote Sensing.

*Beginning on May 1, 1975

(c) Develop and Test Remote Sensing Techniques

At present investigations by the GRSU are nearing completion relative to remote sensing techniques best suited to (1) Cropland Mapping; (2) Crop Identification; (3) Water Demand Prediction; (4) Detection and Analysis of Salinity Areas; and (5) Detection and Analysis of Perched Water Areas. The determination of parameters that are critical to agriculturally oriented water demand models also is essentially complete. Remote sensing techniques have now been evaluated for most of the major model inputs that originally appeared amenable to such methods. Specific procedures are still being refined, however, in this phase of the work. Parallel to this, conventional methods are being investigated, to facilitate cost-effective comparisons with remote sensing techniques. It is anticipated that all remaining aspects of this phase of the work could be brought to a satisfactory state of completion by about April, 1977, assuming that funding would continue at the present level. Although not related in any simple manner to water demand, perched water and associated high soil salinity are major water resource considerations in the San Joaquin Valley. We have investigated various techniques, both manual and automated, for assessing soil salinity crop damage and have found it an extremely complex problem. Results are encouraging, however, and with the continued cooperation of several individuals and organizations in Kern County we hope to further refine and verify our procedures. The time frame for these efforts is very closely tied to future results and as such difficult to predict with any certainty. Similarly, our perched water investigations are currently relying upon receipt in the near future of thermal imagery; the results of this mission will strongly dictate the need for any additional efforts.

(d) Determine Costs of Information-Gathering Using Conventional and Remote Sensing-Aided Methods (See Section (e) below.)

(e) Compare Remote Sensing Techniques with Conventional Ones. Draw Conclusions Regarding Cost-Effectiveness

This phase of our work, like the preceding one, necessitates further testing and refining of ways in which remote sensing can best be used as an aid to providing information relative to water demand while at the same time providing efficient interfacing with current systems. Such an effort will require application of certain of these techniques to areas analogous to our primary water demand test sites, but in which more detailed information about water demand (and over a longer period of time) is available. Furthermore, since it is meaningless to consider the cost-effectiveness of a remote sensing-aided system that may never by used, an expanded program of technology transfer is envisaged for the period May 1, 1976 - April 30, 1977.

This expanded program will be accomplished primarily through our continued involvement with such potential users as the California Department of Water Resources and the Kern County Water Agency.

(f) Analyze Cost-Benefit Impact on Society Resulting from Changes in Water Demand Information Due to Application of Remote Sensing Techniques

The analysis of economic impacts likely to result from changes in water demand information is proving difficult. Further information relative to joint efforts involved in this task appear in the Hoos section, following.

2. The Bowden Group (Riverside Campus)

(a) Continued Water Supply Model Definition and Performance Documentation

In relation to the long-term water demands of the Upper Santa Ana River Drainage Basin (which is the primary test site for the Bowden Group) the most important drivers of the water demand model are those involving agriculture. Three projects need completion and, indeed, can be completed during the period May 1, 1976 - April 30, 1977, provided that our present funding level under the grant is continued. These are (1) monitoring vineyard abandonment, an important factor in relation to water supply since vineyards require 2.1 acre-feet (.26 hectare-meters) of water per season and are fast giving way to airports, motor speedways, steel plant slag piles, and other developments having much different water demands; (2) monitoring the relocation of citrus crops which are coming back into the area (now that new sources of water are becoming available) and which, by requiring year around irrigation, have a stabilized water demand different from that of most other crops; and (3) determining the fallow season of irrigated fields (during which no irrigation water is needed) thereby improving the estimate of water demand for agricultural purposes, season-by-season, as specifically requested by the California Department of Water Resources.

(b) Sensitivity Analysis for Critical Parameters in Water Demand Models

Work under this task, as performed by the Bowden group. will continue to parallel that of other participants under this integrated study, as previously described. Specifically, for each of the critical parameters that are applicable in the Upper Santa Ana River Drainage Basin a determination will be made of the percentage change in water demand associated with a given percentage change in the parameter, itself.

(c) Develop and Test Remote Sensing Techniques

As indicated in section (a), preceding, a significant amount of work still must be done by the Bowden group in developing and testing remote sensing techniques for monitoring vineyard abandonment, the relocation of citrus crops, and the fallow season of irrigated fields, all of which are primary drivers with respect to the water demand model. All of this additional work can be completed within the May 1, 1976 to April 30, 1977 time frame, providing that the present level of grant funding is continued. In addition, work presently underway relative to polygon overlay updating techniques, (based on remote-sensing-derived information) can be completed during that same time frame. To employ these labor-saving techniques and achieve high orders of accuracy, the remote-sensing-derived data, both qualitative and spatial, in a land use information system are organized in such a way as to facilitate machine analysis. Key to this process is a determination of the x and y coordinates of each delineated polygon so that machine-aided techniques can produce land use, or other, map overlays. The same techniques can also provide periodic updates to these overlays and, by providing new area calculations, can facilitate the analysis of change in land use and in associated water demand, area-by-area.

(d) Determine Costs of Information-Gathering Using Conventional and Remote Sensing-Aided Methods

(See Section (d) under the Hoos Group, which follows)

(e) Compare Remote Sensing Techniques with Conventional Ones. Draw Conclusions Regarding Cost-Effectiveness

(See f, below.)

(f) Analyze Cost-Benefit Impact on Society Resulting from Changes in Water Demand Information Due to Application of Remote Sensing Techniques.

Completion of this on-going work (including that under (e), above) will entail further testing and refining of ways in which remote sensing can best be used in providing water demand information. Much of this work is being done in response to highly specific requests by the California Department of Water Resources, the Los Angeles Metropolitan Water District, and other important users of water demand information, the better to ensure that any modifications proposed by our group will permit efficient interfacing with their current systems. It is in this respect that a parallel effort of technology transfer on the part of the Bowden group will continue. As a result, it is anticipated that (1) most of the tests remaining to be conducted under tasks (e) and (f)

can be completed by the Bowden group during the May 1, 1976 - April 30, 1977 time frame, and (2) such additional tests of a similar nature that would need to be performed after that period would be funded and performed primarily by the potential user agency, with only limited involvement by U.C. scientists. Continuing involvement by the Hoos group, particularly with respect to item (f), is envisaged, as described later.

3. The Hoos Group - (Berkeley Campus)

(a) Continued Water Demand Decision Framework and Performance Documentation

Involvement by the Hoos group in this task would be as implied under the same heading of the preceding two sections which deal, respectively, with the Geography Remote Sensing Unit (Santa Barbara Campus) and the Bowden group (Riverside Campus).

(b) Sensitivity Analysis for Critical Parameters in Water Demand Models

(The statement appearing under (a), above, is equally applicable here.)

(c) Evaluate the Potential Social Impacts Resulting from Changes in Water Demand Information Due to Application of Remote Sensing Techniques

The comments appearing in part 3(c) of section A, relative to participation of the Hoos group in this type of study, are as applicable to our water demand studies as in our water supply studies, i.e.: (1) a major degree of integration in this overall "integrated" study is ensured by such participation of the Hoos group in both the water supply and water demand aspects of our study; and (2) as with the earlier phases of our work, we consider that our leadership in the task listed here could terminate by April 30, 1977 even though certain aspects of it might later profitably be conducted under sponsorship of such using agencies as the California Department of Water Resources, the Kern County Water Agency, and the Los Angeles Metropolitan Water District, with only limited involvement by University of California scientists.

C. PREPARATION OF A PROCEDURAL MANUAL

With a view to maximizing the prospect that large numbers of water resource managers will soon be led to properly employ modern remote sensing techniques, we propose to prepare a Procedural Manual for their use. This Manual will set forth in clear, step-wise fashion, the procedure that should be followed in collecting, analyzing, storing, retrieving, and using remote sensing data, the better to satisfy the informational requirements of those who manage water resources.

In successive sections of this manual a brief but succinct disclosure will be made relative to each of the following topics as applied to the inventory, monitoring and management of water resources:

(1) the proper use of multiband and multidate remote sensing data.

(2) the design and implementation of multistage sampling techniques

(3) the design and use of remote sensing-aided models that will permit more accurate and cost-effective forecasts to be made of water supply and water demand, area-by-area, than has heretofore been possible.

(4) the various means by which remote sensing-derived information on water resources can be effectively displayed in order to facilitate the comprehension and use of such information by those who manage water resources.

(5) the cost, time and accuracy considerations that determine which of several means and techniques should be employed in acquiring information useful to the manager of water resources.

(6) specific case studies suitably illustrated, and described in such a way as to show the interplay and practical importance of the foregoing considerations.

Conversations which we already have had with prospective users of such a manual have led to enthusiastic responses and to the following significant suggestion which they have conveyed to us: There is likely to be a need for such a manual both in an abbreviated form and in a form which provides much fuller treatment of each procedural step and which is more fully illustrated. We, therefore, propose to prepare both an abridged version and an unabridged version of the Procedural Manual. In so doing, we will draw on all of the experience we have gained to date both on our NASA-funded grant and on various other remote sensing projects.